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Optimal Capital Income Taxation with Means-tested Benefits

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Optimal Capital Income Taxation with Means-tested Benefits *

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Abstract

This paper studies the interaction between capital income taxation and a means tested age pension in the context of an overlapping generations model, calibrated to the UK economy. Recent literature has suggested a rehabilitation of capital income taxation predicated on the idea that a capital income tax may be a partial substitute for the optimal age-based taxes when they are infeasible. This leads naturally to the conjecture that a publicly funded age pension contingent upon holdings of capital or capital income may have a similar effect. We formalize this using a stochastic OLG model with multiple individuals differentiated by labour productivity and pension entitlements. Our results document that the existence of a social insurance program financed from general revenue puts an upward pressure on the optimal capital income tax rate. We also show that there is a negative relation between taper (benefit-reduction) and optimal capital income tax rates. The potential welfare gain from optimizing capital taxation in the presence of a universal retirement transfer system is relatively higher. However, when the transfer is substantially means tested, the gain is lower, because the means test effectively operates as a tax on retirement capital.

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1 Introduction

Over the last decade or so, the 1980s results of Judd and Chamley (Judd (1985) & Chamley (1986)) that a zero capital income tax rate is optimal, have been severely qualified. There are two major explanations. The first relates to restrictions on instruments. When consumer preference is placed in a life-cycle framework, individuals vary their optimal consumption-work plan over the cycle, and age specific taxation is not available, capital income taxation may be a second best solution.[1] Secondly, if markets are incomplete, resulting in liquidity constraints and/or uninsurable idiosyncratic income risk, then a non-zero capital income tax may dominate a zero capital tax environment, because higher net-of-tax labour earnings relax liquidity constraints and/or provide more opportunity for self-insurance. Conesa *et al.* (2009) show that when these features of preferences, policy restrictions and markets are represented in overlapping generations (OLG) models of incomplete economies, then the optimal capital income tax rate may be non-zero. They calculate an optimal rate of 36% for the US.

Taking the above observation as a point of departure, this paper studies the impact of means-testing (resource-testing) public pensions, a feasible policy action equivalent to introducing a capital income tax on retirement capital. The UK is one of a number of countries with a means tested pension program: the means-tested social insurance program provides an old age pension income subject to a means testing of income and asset holdings. Over the last several years various reforms have been enacted to the UK means tested pension. It is therefore suitable for our analytic purposes.

This paper contributes to the literature from two perspectives: First, it extends Conesa *et al.* (2009) by adding a means-tested pension program that interacts with the capital income tax rate. Since our main aim is to analyze the interaction between means-tested pension programs and taxes on capital income, we intentionally kept our benchmark model similar to that of Conesa *et al.* (2009).[2] Yet, we chose to calibrate our model to the UK economy since the UK has already a means-tested pension program. As a result, we were able to assign real values to the pension program parameters. This allows us to determine the effect of an implicit tax on capital income on the optimal capital income tax rate. Second, it carries Sefton & van de Ven (2009)'s study on the relation between means-tested benefits and taxation to a richer modeling environment so that we can quantify the optimal income tax rates as in Conesa *et al.* (2009) for the UK.

In means tested pension programs, the retirement benefit function depends on individual income at the time the benefits are paid. This dependence is assumed to be linear, with

[1] Gervais (2012) shows that a progressive tax on labor income can also be used to mimic an optimal age-dependent tax policy.

[2] As in Conesa *et al.* (2009), we ignore the transitional dynamics; use lognormal distributions of earnings shocks; and ignore the female labor supply decisions. In a recent paper Fehr & Kindermann (2015) show that incorporating transitional dynamics generate much lower optimal capital income tax rates. Guvenen *et al.* (2015) show that earnings shocks display substantial deviations from lognormality- the standard assumption in the incomplete markets. Kaygusuz (2015) show that incorporating female supply decision to tax-transfer models has also important implications.

a constant negative slope (taper rate) i.e., the benefits are reduced by a fraction of current income. The taper cannot turn the benefits negative. This introduces non-linearity. Since dissaving is a source of income later in the life cycle, the taper can act as a non-linear tax on savings.

We start with a benchmark model in which the taper rate is 100% and the income tax system (baseline tax system) mimics that of the UK and calibrate the model economy to the UK data. Keeping everything else constant, we calculate the optimal tax system in this economy. Later we reduce the taper rate to 40% keeping the baseline tax system intact and calculate the associated optimal tax system. Since the UK reformed the means-tested pension program by reducing the taper rate from 100% to 40% in 2003, we call the former the pre-reform taper rate and the latter the post-reform rate. We repeat our analysis assuming a zero taper (universal pension program) and the complete removal of the means-tested pension program as well.

We find that the optimal capital income tax rates in both pre-and post-reform economies in the UK are significantly positive at 33% and 34% respectively. Furthermore, we show that the optimal capital income tax rate is 37% and 31% in the universal pension and the complete removal settings, respectively. The complete removal setting is the closest to that of Conesa *et al.* (2009). From here we can see that having means-tested and universal pension programs put upward pressure on the optimal capital income tax rate since they increase the government's revenue requirement.

More importantly, we show that there is a negative relation between taper rates and the optimal capital income tax rate. The taper rate substitutes for the proportional capital tax: lower taper rates lead the planner to pick higher capital tax rates; higher taper rates reduce the need for linear capital taxes and the planner picks lower rates. The intuition is as follows: First, a lower taper rate implies a higher revenue requirement (revenue effect). The revenue effect is a mechanical reduction in the revenue needed to be raised when the taper is higher. The higher revenue requirement leads to higher capital and labor tax rates. Second, the means-tested pension program acts as a non-linear capital income tax by only targeting the individuals over the retirement age and reduces the need for the linear tax (*substitution effect*). Thus, when the taper rate is higher, the optimal capital income tax rate becomes relatively lower. Third, as in Peterman (2013a), the optimal tax on capital increases when the size of the means-tested pension program increases as a result of a decrease in the taper rate (*pension benefit effect*). Revenue and pension benefit effects are somehow related. Lower taper rates imply that more individuals receive more generous means-tested benefits. Hence, the government needs to increase taxes on capital and labor incomes to fulfill its revenue requirement. Since retired individuals now get higher benefits, the government would prefer to tax capital income more to unwind some of generous retirement benefits.

Interestingly, when the taper rate is 100%, the welfare improvement as a result of changing the tax system from the baseline to the optimal one is the lowest among all the settings we considered. This result further highlights the role of a means-tested pension program as an effective way of targeting capital income. It has also been shown that a similar pattern of life-cycle asset holdings can be generated by either reforming the baseline tax system or changing the taper rate. From this perspective, the existence of a means-tested pension program in the economy enhances the policy maker's options.

Our results suggest not just that positive capital income taxation may be welfare improving, but that means testing publicly financed retirement pensions has a similar impact. Means testing may not only reduce the revenue requirement for a given pension benefit, but improve resource allocation and aggregate welfare. This is of special interest in light of current global debate on public pension reform and taxation.

Although social insurance benefits have been means-tested for a long time, these policies have only recently attracted systematic attention from economists. By using a partial equilibrium model with a binary labor-leisure choice Sefton *et al.* (2008) and Sefton & van de Ven (2009) analyzed the welfare implications of the means-testing of pension benefits and the interactions between various tax schemes and means-tested benefits respectively. Kumru & Piggott (2009) extend Sefton *et al.* (2008)'s model to analyze the implications of means-tested benefits in a general equilibrium framework. Both studies report that means-testing increases welfare. Golosov & Tsyvinski (2006) analyze the implications of asset (means) testing disability insurance and find significant welfare gains from asset testing. In a recent paper, Kitao (2014) analyzes various social security reform proposals including means-testing of benefits and shows that means-testing might not be a good idea.

There is also a growing literature that investigates the determinants of the tax rate on capital income by extending Conesa *et al.* (2009) from various channels. Peterman (2013a) highlights the impact of changing two assumptions: variable Frisch elasticity of labor supply and taxing accidental bequests at the same rate. These changes cause the optimal tax on capital to drop by almost half. Nakajima (2010) incorporates a housing asset into a model similar to that of Conesa *et al.* (2009) and shows that the optimal capital income tax rate in the model with housing is 1%. Kuklik (2011) extends Conesa *et al.* (2009)'s model by adding two additional elements: a non-linear mapping between hours worked and wages and inter-vivos transfers and shows that the optimal capital income tax rate in the US is 7.4%. Peterman (2013b) and Peterman (2015) show that incorporating endogenous retirement decision and learning by doing also cause increases in optimal capital tax rates. Shourideh & Troshkin (2012) follow the empirically driven Mirrleesian literature and provide an analysis of pension system as an integral part of the overall income tax code. Although we use a different methodology, our study is related to that of Shourideh & Troshkin (2012) in terms of analyzing the pension system and the income tax code together. Incorporating the transition path from the status quo to the reformed steady state can also matter for the optimal capital tax rate. Fehr & Kindermann (2015) show that the optimal capital tax rate is significantly lower when transitional cohorts explicitly taken into account. All these findings suggest that many different factors would affect the optimal capital income tax rate. There is also a line of study that extends Conesa *et al.* (2009) by analyzing the various income tax reforms: Kitao (2010) studies the implications of the reform proposal that replaces the current US income tax system with a system that includes a labor-dependent capital income tax and shows that the reform proposal creates a significant welfare gain. Fukushima (2010) studies the implications of a policy reform which replaces an optimal flat tax with an optimal nonlinear tax that is age and history dependent and shows that welfare increases substantially.

The rest of the paper is organized as follows: In sections 2 and 3, we present the model economy and the calibration process, respectively. Section 4 presents the results and Section 5 concludes. The details of numerical analysis and the remaining figures are reported in the Appendix.

2 The Model Economy

We use a general equilibrium OLG model economy with uninsured idiosyncratic shocks to labor productivity and mortality. The main features of our model follow those of Conesa *et al.* (2009). Our model differs from that of Conesa *et al.* (2009) from two directions. First, the model incorporates a means-tested pension program. Second, our model economy is calibrated to the UK. In terms of modeling the public sector, we follow Sefton *et al.* (2008) and Sefton & van de Ven (2009).

2.1 Demographics

Time is discrete. Each period a new generation is born. Individuals live a maximum of J periods. The population grows at a constant rate n. All individuals face a probability (s_j) of surviving from age j to $j+1$ conditional on surviving up to age j. Individuals retire at exogenously determined retirement age $j^*$and receive relevant pension benefits.

2.2 Endowments

Let $j \in \hat{J} = \{1, 2, ...J\}$ denote age. An individual's labor productivity in a given period depends on age, permanent differences in productivity due to differences in education or abilities, and an idiosyncratic productivity shock to the individual's labor productivity. In other words, agents are heterogenous in terms of labor productivity. Age-dependent labor productivity is denoted by $\bar{e}_j$. Each individual is born with a permanent ability type $\hat{e}_i \in \hat{E} = \{\hat{e}_1, \hat{e}_2, ..., \hat{e}_m\}$ with probability $p_i > 0$. Individuals face an idiosyncratic shock $\psi \in \Psi = \{\psi_1, \psi_2, ..., \psi_n\}$ to labor productivity. The stochastic process for ψ is identical and independent across individuals and follows a finite-state Markov process with a stationary distribution over time: $Q(\psi, \Psi) = \Pr(\psi' \in \Psi | \psi)$. We assume that Q consists of only strictly positive entries and hence, Π is the unique, strictly positive, invariant distribution associated with Q. Initially each individual has the same average stochastic productivity given by $\overline{\psi} = \sum_{\psi} \psi \Pi(\psi)$, where $\Pi(\psi)$ is the probability of ψ. Hence, an ability type $\hat{e}_i$ individual's labor supply at age j in terms of efficiency units are written as $\bar{e}_j \hat{e}_i \psi l_j$, where l_j is hours of work. Let $a \in A \subset \mathbb{R}^+$, where a denotes asset holdings. A is a compact set. Its upper bound never binds and its lower bound is equal to zero. We define the space of individuals' state variables as follows: $X = \hat{J} \times A \times \hat{E} \times \Psi$. Note that at any time t, an individual is characterized by the state set $x = (j, a, \hat{e}_i, \psi) \in X$. Let M be the Borel σ-algebra generated by X and let $B \in M$. Define μ as the probability measure over M. Hence, we can represent individuals' type distribution by the probability space (X, M, μ).

2.3 Preferences

Individuals have preferences over consumption and leisure sequence $\{c_j, (1-l_j)\}_{j=1}^{J}$ represented by a standard time separable utility function:

$$E\left[\sum_{j=1}^{J} \beta^{j-1} u(c_j, 1-l_j)\right], \tag{1}$$

where E is the expectation operator and β is the time-discount factor. Expectations are taken over the stochastic processes that govern idiosyncratic labor productivity risk and longevity.

2.4 Technology

A representative firm produces output Y at time t by using aggregate labor input measured in efficiency units (L) and aggregate capital stock (K). The technology is represented by a Cobb-Douglas constant returns to scale production function:

$$Y_t = A_t K_t^{\alpha} L_t^{1-\alpha}. \tag{2}$$

A_t is the level of total factor productivity. Output shares of capital stock and labor input are given by α and $(1-\alpha)$ respectively. The capital stock depreciates at a constant rate $\delta \in (0,1)$. The representative firm maximizes its profit by setting wage and rental rates equal to the marginal products of labor and capital respectively:

$$w_t = A_t(1-\alpha)(\frac{K_t}{L_t})^{\alpha}, \tag{3}$$

$$r_t = A_t \alpha (\frac{K_t}{L_t})^{\alpha-1}. \tag{4}$$

2.5 The Public Sector

The government runs a public pension system comprising an earnings-dependent Pay As You Go (PAYG) pension and a means-tested pension programs. Since individuals face stochastic life-span and private annuity markets are closed by assumption, a fraction of the population will leave accidental bequests. The government confiscates all accidental bequests and delivers them to the remaining population in a lump-sum manner. We denote these transfers by η_t. Finally, the government faces a sequence of exogenously given consumption expenditures $\{G_t\}_{t=1}^{\infty}$. To finance its consumption and means-tested pension program expenditures, the government levies taxes on capital income, labor income, and consumption. PAYG pension program is self-financing and benefits are financed through payroll tax (τ_p) collections.

A j year old individual's labor income, capital income, and gross taxable income in year t are given as follows:

$$\begin{aligned} y_{l,t} &= w_t \bar{e}_j \hat{e}_i \psi l_j, \\ y_{k,,t} &= r_t(a_t + \eta_t), \\ y_t &= y_{l,t} + y_{k,t}. \end{aligned}$$

The pension program of our model reflects the basic features of that of the UK.[3] Individuals who reach retirement age receive a PAYG pension benefit $b_t(x)$ at time t and might be entitled to additional means-tested pension benefits depending on their private income.[4] The PAYG program benefits are calculated as follows:

$$b_t(x) = \theta \frac{\sum_{j=1}^{j^*-1} y_{l,j}}{j^* - 1}, \tag{5}$$

where $y_{l,j}$ is an individual's labor income at age j and θ is the PAYG replacement rate.

Means-tested benefits are determined as follows:

$$b_t^*(x) = \max[\overline{b_t} - \phi y_t, 0], \tag{6}$$

where $b_t^*(x)$ is the means-tested benefit received by a retired individual at time t; $\overline{b_t}$ is the maximum amount of means-tested pension benefits that can be received at time t; and ϕ is the taper (benefit reduction) rate.

Following Conesa *et al.* (2009) and Nakajima (2010) we use the functional form introduced by Gouveia & Strauss (1994) to capture the progressivity of the income tax rate in our baseline economies:

$$T_t(y_t) = \kappa_0(y_t - (y_t^{-\kappa_1} + \kappa_2)^{-1/\kappa_1}), \tag{7}$$

where κ_0, κ_1, and κ_2 are parameters. In this specification, while the level of average tax

[3] The UK pension system consists of three tiers: The universal flat rate Basic State Pension (BSP), mandatory second tier [individuals must either pay contributions to the state run PAYG earnings related scheme (State Second Pension) or pay contributions into a privately funded scheme], and means-tested benefits. Our model is a simplified version of the UK system. The first tier is the earnings-related PAYG system which incorporates the UK's first and second tier benefits and the second tier is the means-tested pension program that mimics the UK's means-tested pension program. See Sefton *et al.* (2008) for a detailed exposition of the UK public pension program.

[4] In our model individuals can receive the means-tested benefits only after they reach the exogenously determined retirement age (equivalent to the state pension age). However, in the UK, individuals might be entitled to means-tested benefits before they reach the state pension age. The actual means-tested benefits are also subject to asset tests. Individuals receive the minimum benefits determined by asset and income tests. Notice that in the model, after retirement individuals do not work. Thus, retirement income comes from two major sources: asset holdings and the first tier PAYG pension benefits. This implies that the income test is tighter then the asset test since the test base is wider in the former i.e. it always generates lower benefits than the asset test in our environment.

rate is controlled by κ_0, the progressivity of the tax code is controlled by κ_1 and κ_2. This functional form has been extensively employed in the quantitative public finance literature. See for example, Castañeda *et al.* (1998), Rull (1999), and Conesa & Krueger (2006).[5]

In our calculation of the optimal tax rates, we assume that the capital income tax rate is proportional and denoted by τ_k and the labor income tax rate is determined by the same Gouveia-Strauss tax function as follows:

$$\begin{aligned} T_t(y_k) &= \tau_k y_{k,t} \text{ and} \\ T_t(y_l) &= \kappa_0(y_{l,t} - (y_{l,t}^{-\kappa_1} + \kappa_2)^{-1/\kappa_1}). \end{aligned} \tag{8}$$

In addition to taxes on capital and labor incomes, the government taxes consumption expenditures at an exogenously given proportional rate τ_c, which does not change in all experiments.

2.6 An Individual's Decision Problem

In the baseline (status quo), individuals face the following budget constraint:

$$\left\{ \begin{array}{c} (1+\tau_c)c + a' \leq y_t - T_t(y_t) - \tau_p y_{l,t} \text{ when } j < j^* \\ (1+\tau_c)c + a' \leq y_t - T_t(y_t) + b_t(x) + b_t^*(x) \text{ when } j \geq j^* \\ (1+\tau_c)c = y_t - T_t(y_t) + b_t(x) + b_t^*(x) \text{ when } j = J. \end{array} \right\} \tag{9}$$

In the optimal system, individuals face the following budget constraint:

$$\left\{ \begin{array}{c} (1+\tau_c)c + a' \leq (1+r_t(1-\tau_k))(a+\eta_t) + y_{l,t} - T_t(y_{l,t}) - \tau_p y_{l,t} \text{ when } j < j^* \\ (1+\tau_c)c + a' \leq (1+r_t(1-\tau_k))(a+\eta_t) + b_t(x) + b_t^*(x) \text{ when } j \geq j^* \\ (1+\tau_c)c = (1+r_t(1-\tau_k))(a+\eta_t) + b_t(x) + b_t^*(x) \text{ when } j = J, \end{array} \right\} \tag{10}$$

where the next period's variables are denoted by a prime. For instance, a' denotes the next period's asset holdings.

Individuals also face the following borrowing constraint:

$$a' \geq 0. \tag{11}$$

The decision problem of an individual in our model economy can be written as a dynamic programming problem. Denoting the value function of the individual at time t by V_t, the decision problem is represented by the following problem:

[5] Gouveia-Strauss tax function comprises an array of progressive, proportional, and regressive tax schedules: The limiting values of marginal and average tax rates are equal to κ_0 ($\lim_{y\to\infty} \frac{T(y)}{y} = \lim_{y\to\infty} T'(y) = \kappa_0$); when $\kappa_1 = -1$, the amount of tax paid does not depend on income ($T(y) = -\kappa_0\kappa_1$); when $\kappa_1 \to 0$, the tax system is propostional ($T(y) = \kappa_0 y$); and when $\kappa_1 > 1$, the tax system is progressive since aveage and marginal taxes are strictly increasing function of income ($\frac{T(y)}{y} = \kappa_0(1 - (1+\kappa_2 y^{\kappa_1})^{-\frac{1}{\kappa_1}}$ and $T'(y) = \kappa_0(1-(1+\kappa_2 y^{\kappa_1})^{-\frac{1}{\kappa_1}-1})$).

$$V_t(x) = \max_{c,l}\{u(c, 1-l) + \beta s_j \int V_{t+1}(x')Q(\psi, d\psi')\} \tag{12}$$

subject to the aforementioned budget and borrowing constraints.

2.7 Equilibrium

Our competitive and stationary competitive equilibrium definition follows Auerbach & Kotlikoff (1987), Conesa *et al.* (2009), and Nakajima (2010).

Definition 1 *Given sequences of government expenditures* $\{G_t\}_{t=1}^{\infty}$, *consumption tax rates* $\{t_c\}_{t=1}^{\infty}$, *payroll tax rate* $\{\tau_p\}_{t=1}^{\infty}$, *maximum amount of means-tested benefits can be received* $\{\overline{b_t}\}_{t=1}^{\infty}$, *taper rate* $\{\phi\}_{t=1}^{\infty}$ *and initial conditions* K_1 *and* Φ_1, *a competitive equilibrium is a sequence of value functions* $\{V_t\}_{t=1}^{\infty}$ *and optimal decision rules* $\{c_t, a'_t, l_t\}_{t=1}^{\infty}$, *measures* $\{\Phi_t\}_{t=1}^{\infty}$, *aggregate stock of capital and aggregate labor supply* $\{K_t, L_t\}_{t=1}^{\infty}$, *prices* $\{r_t, w_t\}_{t=1}^{\infty}$, *transfers* $\{\eta_t\}_{t=1}^{\infty}$, *and tax policies* $\{\tau_{k,t}, T_t(.)\}_{t=1}^{\infty}$ *such that*

1. $\{V_t\}_{t=1}^{\infty}$ *is a solution to the maximization problem defined above by 12. Associated optimal decision rules are given by the sequence* $\{c_t, a'_t, l_t\}_{t=1}^{\infty}$.

2. *The representative firm maximizes its profit according to the equations 3 and 4.*

3. *All markets clear:*

   (a) $K_t = \int a\Phi_t(dj \times da \times d\hat{e}_i \times d\psi)$,

   (b) $L_t = \int \bar{e}_j \hat{e}_i \psi l_j(j, a, \hat{e}_i, \psi)\Phi_t(dj \times da \times d\hat{e}_i \times d\psi)$,

   (c) $C_t = \int c_t(j, a, \hat{e}, \psi)\Phi_t(dj \times da \times d\hat{e}_i \times d\psi)$

   (d) $C_t + K_{t+1} + G_t = Y_t + (1-\delta)K_t$.

4. *Law of motion*

   (a) *for all* $\hat{J}$ *such that* $1 \notin \hat{J}$ *is given by* $\Phi_{t+1}(\hat{J} \times A \times \hat{E} \times \Psi) = \int P_t((j, a, \hat{e}_i, \psi); \hat{J} \times A \times \hat{E} \times \Psi)\Phi_t(dj \times da \times d\hat{e}_i \times d\psi)$, *where*

   . $P_t((j, a, \hat{e}_i, \psi); \hat{J} \times A \times \hat{E} \times \Psi) = \begin{cases} Q(\psi, \Psi)s_j \text{ if } j+1 \in J, a'_t(j, a, \hat{e}_i, \psi) \in A, \hat{e}_i \in \hat{E} \\ 0 \text{ else} \end{cases}$

   (b) *for* $\hat{J} = \{1\}$*:* $\Phi_{t+1}(\{1\} \times A \times \hat{E} \times \Psi) = (1+n)^t \begin{cases} \sum_{\hat{e}_i \in \hat{E}} p_{\hat{e}_i} \text{ if } 0 \in A, \overline{\psi} \in \Psi \\ 0 \text{ else} \end{cases}$

5. *Transfers are given by* $\eta_{t+1} \int \Phi_{t+1}(dj \times da \times d\hat{e}_i \times d\psi) = \int (1-s_j)a'_t(j, a, \hat{e}_i, \psi)\Phi_t(dj \times da \times d\hat{e}_i \times d\psi)$.

6. *PAYG pension program is self financing:* $\tau_{p,t} \int y_{l,t}\Phi_t(\{1, ..., j^*-1\} \times da \times d\hat{e}_i \times d\psi) = \int b_t(j, a, \hat{e}_i, \psi)\Phi_t(\{j^*, ..., J\} \times da \times d\hat{e}_i \times d\psi)$.

7. *Means-tested pension payments are given by* $Pen_t = \int b_t^*(j, a, \hat{e}_i, \psi)\Phi_t((dj \times da \times d\hat{e}_i \times d\psi)$.

8. *Government runs a balanced budget:* $G_t + Pen_t = \int T_t[y_{l,t}]\Phi_t(dj \times da \times d\hat{e}_i \times d\psi) + \int \tau_k r_t(a + \eta_t)\Phi_t(dj \times da \times d\hat{e}_i \times d\psi) + \tau_c \int c_t \Phi_t(dj \times da \times d\hat{e}_i \times d\psi)$.

Definition 2 *A stationary equilibrium is a competitive equilibrium in which per capita variables and functions, prices, and policies are constant. Aggregate variables grow at the constant rate* n.

3 Calibration

This section defines the parameter values of our model. The values of calibrated parameters for the benchmark economy are presented in Table 1.

Demographics Each model period corresponds to a year. Individuals are born at a real age of 20 (model age of 1) and they can live up to a maximum real life age of 100 (model age of 81). The population growth rate is assumed to be equal to the long-term average growth rate of the UK's population i.e. $n = 0.5\%$ [National Statistics (2009a)].[6] The sequence of conditional survival probabilities in the model, s_j is set equal to the sequence of conditional survival probabilities of men in the UK using $2002 - 2004$ data [National Statistics (2009b)]. The mandatory retirement age is 65 (model age of 46), which is equal to the UK's state pension access age for men.

Endowments An individual's wage income at time t, expressed in logarithms is given by $\log(w_t) + \log(\bar{e}_j) + \log(\hat{e}_i) + \log(\psi)$. The age dependent efficiency index, $\bar{e}_j$ is set as follows: Robinson (2003) estimates age-earnings profiles for different educational levels by using various specifications. We take her estimates of weekly earnings for different levels of experience, normalize the data by setting the value of weekly earnings for a man with one year's experience to 1 and interpolate the normalized data by using the spline method for missing values.[7] There are two ability types: $\hat{e}_1 = e^{-\sigma_{\hat{e}}}$ and $\hat{e}_2 = e^{\sigma_{\hat{e}}}$, where $E(\log(\hat{e}_i)) = 0$, $\text{var}(\log(\hat{e}_i)) = \sigma_{\hat{e}}^2$, and the population mass, $p_i = 1/2$. The stochastic component of the idiosyncratic part of wages follows the $AR(1)$ process, $\log(\psi') = \rho \log(\psi) + \epsilon$, where $\epsilon \sim N(0, \sigma_\psi^2)$. AR(1) process is approximated by using a finite-state first order Markov process with seven states. Blundell & Etheridge (2008) calculate the variance of permanent and temporary shocks to earnings in the UK as approximately 0.08 and 0.05 in 2003. Hence, we set $\sigma_{\hat{e}}^2$=0.08 and $\sigma_\psi^2 = 0.05$. Following Sefton *et al.* (2008), we set the persistence parameter, $\rho = 0.990$.

[6] This is the average annual population growth rate between 2001 and 2007.

[7] Robinson (2003) estimates weekly earnings for both men and women according to whether they have attained a low, medium, or high educational level. She uses quadratic, cubic, and quartic specifications. We use the values of her estimates for men in the group with the least amount of education which is calculated using a quadratic specification.

Preferences Individuals have time-separable preferences over consumption and leisure. We use the following standard Cobb-Douglas specification:

$$u(c, 1-l) = \frac{(c^{\upsilon}(1-l)^{1-\upsilon})^{1-\sigma}}{1-\sigma}. \tag{13}$$

The value of υ determines the importance of consumption relative to leisure and the value of σ determines the level of risk aversion. Inter-temporal elasticity of substitution in consumption (IES) is equal to $\frac{1}{1+\sigma\upsilon-\upsilon}$. We set $\sigma = 4$ and pin down $\upsilon = 0.377$ by setting IES=0.5, which is commonly accepted value for IES in the literature. By setting $\upsilon = 0.377$ we make sure that average hours worked is 1/3 of the disposable time endowment.[8] We set time-discount factor $\beta = 0.965$ in the benchmark model to generate the capital-output ratio of approximately 2.8.[9]

Technology Batini *et al.* (2000) report the values of labor's share of income $(1-\alpha)$ in the UK between 1970 and 1995. The values fluctuate between 68% and 74% and their average is approximately 70%. Hence, we set the value of labor income share to 0.70. Weale (2004) estimates the capital depreciation rate in the UK in 2002 to be 4.82%. We use the same value for δ. The technology level, A can be chosen freely and we set it to 1.

Government Policy We set the value of the maximum amount of means-tested benefits that can be received, $\bar{b}$ to 5% of output per capita in the model. This benefit is reduced by a taper rate applied to any private income including PAYG pension benefits. We variously set the value of the taper rate, ϕ to 100%, 40%, and 0% in our analysis. We set government expenditure G to 22% of GDP.

We estimate the parameters of the Gouveia-Strauss tax function by using UK income tax data as $(\kappa_0, \kappa_1, \kappa_2) = (.521, .701, .317)$. The details of the estimation are given in Appendix. In our baseline calibrations, we set the income tax function's parameters' κ_0 and κ_1 equal to our estimated values where κ_2 is determined endogenously by the budget balance condition i.e. the parameter κ_2 adjusts to ensure that the government's budget is balanced. In our search for the optimal tax system we set the values of the labor income tax function's parameters κ_1 and κ_2 equal to those of the baseline's income tax function (i.e. we keep the level of progressivity constant) with κ_0 determined endogenously. We set the consumption tax rate τ_c to 5%.

4 Results

4.1 Computational Experiment and Welfare Measures

In our experiments, as in Conesa *et al.* (2009) and Nakajima (2010), the government optimizes over the two tax functions given by equation 8. More precisely, the government maximizes

[8] The Frisch Elasticity=$\frac{1-l}{l}[\frac{1-\gamma(1-\sigma)}{\sigma}]$, which is equal to 1 under our parameter value choices.

[9] Doblin (1991) estimates the long-run capital-output ratio for the UK as 2.8.

Demographics	
Maximum possible life span J	81 (real age of 100)
Obligatory retirement age j^*	46 (real age of 65)
Growth rate of population n	0.5%
Conditional survival probabilities $\{s_j\}_{j=1}^{J}$	UK 2002 – 2004
Endowments	
Age efficiency profile $\{\bar{e}_j\}_{j=1}^{j^*-1}$	Robinson (2003)
Variance types $\sigma^2_{\hat{e}}$	0.08
Variance shocks σ^2_{ψ}	0.05
Persistence ρ	0.990
Preferences	
Annual discount factor of utility β	0.995
Risk aversion σ	4
Consumption share υ	0.377
Production	
Capital share of the GDP α	0.30
Annual depreciation of capital stock δ	4.82%
Scale parameter A	1
Government	
τ_p	%12.5
Minimum guaranteed pension income $b^{\min}$	5% of output per capita
Taper rate ϕ	100%
Consumption tax rate τ_c	5%
Marginal tax rate κ_0	0.521
Progressivity of labor income tax κ_1	0.701
Progressivity of labor income tax κ_2	0.819
Government expenditures G	22%

Table 1: Parameter Values of The Benchmark Calibration

the ex ante lifetime utility of an individual born into the stationary equilibrium (social welfare function) by choosing $(\kappa_1, \kappa_2, \tau_k)$. The value of parameter κ_0 is determined by budget balance.[10]

$$SWF(\kappa_1, \kappa_2, \tau_k) = \int V_{(\kappa_1,\kappa_2,\tau_k)}(j, a = 0, \hat{e}_i, \psi = \overline{\psi}) d\Phi_{(\kappa_1,\kappa_2,\tau_k)}.$$

It is important to note that the tax reform is revenue neutral i.e. the total tax revenue required to be raised in order to finance government expenditures is the same across optimal and baseline tax cases.

In order to compare welfare across economies with different tax programs, following Conesa *et al.* (2009), we compute the consumption equivalent variation (CEV) which is simply the uniform percentage decrease in consumption required to make an agent indifferent between being born under the optimal tax program (comparison case) relative to being born under the status quo tax system (baseline case). A positive CEV reflects a welfare increase due to the

[10] In our model, as in Nakajima (2010), the marginal tax rate parameter κ_0 balances the government budget. In contrast, in Conesa *et al.* (2009), a progressivity parameter, κ_2 balances the budget.

optimal tax program compared to the baseline case.[11] Our CEV measure can be decomposed into two components: one part that captures the changes in CEV due to changes in consumption from c_0 to c_* and the other part captures the changes in leisure from $(1-l_0)$ to $(1-l_*)$. Each component then can be divided further to capture changes in average consumption (leisure) and distribution of consumption (leisure). In other words, $CEV \approx CEV_C + CEV_L$, where CEV_C and CEV_L denote the changes in CEV due to consumption and leisure respectively. $CEV_C \approx CEV_{CL} + CEV_{CD}$ and $CEV_L \approx CEV_{LL} + CEV_{LD}$, where CEV_{CL} and CEV_{LL} denote changes in CEV due to changes in the level of consumption and leisure respectively and CEV_{CD} and CEV_{LD} denote changes in CEV due to changes in the distribution of consumption and leisure respectively. It can be shown that $CEV_{CL} = (C_*/C_0) - 1$ and $CEV_{LL} = (L_*/L_0) - 1$, where C and L stand for aggregate amounts of consumption and leisure.[12]

In our benchmark economy, we set the taper rate to 100%, which is the pre-reform rate in 2003 in the UK, and calculate total taxes paid by using the baseline tax function. Then we calculate the optimal tax rates for this economy. To explore the implications of a means-tested pension program with capital income taxation, we vary the taper rate by keeping the baseline tax function constant and calculate the optimal tax rates for those economies as well.

4.2 Benchmark Model

First we describe the features of the benchmark economy and the implications of the optimal tax program in this economy. In the baseline case, the income tax system is characterized by (κ_0, κ_1, κ_2)=$(0.521, 0.701, 0.819)$ which reflects the progressive income tax system in the UK implying the income tax system with marginal rate of 52.1% and a and a deduction of £17396 relative to the average income of £26970. In contrast, the optimal tax system is 33% tax rate on capital income (τ_k) and a labor income tax characterized by (κ_0, κ_1, κ_2)=$(0.454, 0.701, 0.819)$ implying the labor income tax is a flat tax with marginal rate of 45.4% and a deduction of £17396 relative to the average income of £26970. As in Conesa *et al.* (2009) and Nakajima (2010), the significantly positive tax on capital income maximizes welfare.[13] The intuition behind taxing capital income with a significantly higher rate is as follows: When the Frisch elasticity varies over the life-cycle, it is optimal to condition labor income taxes on ages. When age-based taxation is not feasible, the positive tax on capital can be used to mimic the optimal age based taxation. This is because a tax on capital income implicitly taxes younger labor income at a relatively higher rate. In addition, the inability to tax accidental bequests is another substantial reason for higher capital income tax rates in Conesa *et al.* (2009) and in this paper (see Peterman (2013a) for a detailed discussion in these issues).

[11] In other words, we calculate welfare by using ex-ante expected utility of newborns in stationary equilibrium [denoted by $W(c,l)$] transformed into consumption units. The welfare consequences of switching from a steady-state allocation (c_0, l_0) to (c_*, l_*) is given by $CEV = [\frac{W(c_*,l_*)}{W(c_0,l_0)}]^{1/\upsilon(1-\sigma)} - 1$.

[12] Details of welfare compositon are given in Conesa *et al.* (2009).

[13] Conesa *et al.* (2009), in a model calibrated to the US economy, find that the optimal tax system is given by a 36% capital income tax rate and a 23% labor income tax rate with a deduction of \$7200. In a similar model, Nakajima (2010) finds that the optimal capital income tax rate is 31%.

Economic Aggregates	Status-quo	Optimal tax system	Change in percent
Average hours worked	0.316	0.330	4.28
Labor supply N	12.452	12.957	3.90
Capital stock K	52.928	53.823	1.66
Output Y	19.221	19.863	3.23
Consumption C	12.511	13.207	5.27
Welfare			Change in percent
CEV			1.34
CEV_C			5.59
CEV_{CL}			5.27
CEV_{CD}			0.32
CEV_L			-4.26
CEV_{LL}			-4.28
CEV_{LD}			0.02
Income Tax System			
τ_k		0.33	
κ_0	0.521	0.454	
κ_1	0.701	0.701	
κ_2	0.819	0.819	

).

Table 2: Economic aggregates and social welfare in status-quo (baseline) and optimal tax system economies when the taper rate is 100%

Table 2 presents equilibrium statistics of the baseline and optimal tax systems and welfare consequences of switching from the baseline tax system to the optimal one. As a consequence of switching from the baseline to the optimal system, all economic aggregates increase significantly. The optimal system's positive effects on saving and labor supply decisions are reflected in higher aggregate output and consumption levels. In our benchmark economy, the highest marginal tax rate is 52.1%. In the optimal system, the taxes on capital income and labor income are lighter relative to the benchmark economy. This, in turn causes an increase in capital and labor supply. Total welfare gain is equivalent to 1.34% increase in consumption at all ages and all states of the world. This value is quite close to the one calculated by Conesa *et al.* (2009). The effects of the optimal system on aggregate labor supply and capital stock differ from those documented in Conesa *et al.* (2009) and Nakajima (2010). In a similar vein, the sources of welfare gain in our model is different from those of Conesa *et al.* (2009) and Nakajima (2010).

In Conesa *et al.* (2009), in the optimal tax system capital drops substantially below the level of the benchmark economy. Consequently aggregate output and aggregate consumption fall as well. This is an immediate consequence of the heavy tax on capital income in the optimal tax system, relative to the benchmark (where the highest marginal tax rate is 25.8 percent). The change in taxes also induces adjustments in labor supply. While average hours worked drop by 0.56 percent, labor efficiency units drop by only 0.11 percent; thus labor supply shifts from less to more productive households. In Nakajima (2010), when the capital income tax rate is lowered from the baseline level of 40% to the optimal level of 31%, the average labor income tax rate has to be increased to guarantee the revenue neutrality. Naturally, capital stock increases, by 2.3%, while labor supply declines by 1.5%. Aggregate output and aggregate consumption decline, by 0.5% and 1.3%, respectively.

In Conesa *et al.* (2009), the improvement in the life-cycle distribution of the consumption and the increase in the level of the amount of leisure taken are the main driving forces behind the total increase in welfare despite the fact that the level of consumption decreases substantially. In Nakajima (2010), the total welfare gain is equivalent to a mere 0.1% increase in consumption in each period. Although the aggregate effect is negative, reflecting the decline in aggregate consumption, the positive redistribution effect more than offsets the negative aggregate effect. The overall size of the welfare gain by moving from the baseline economy to the one with the optimal tax rate is small, because the baseline economy with a 40% capital income tax rate is close to the economy with the optimal capital income tax rate. In our model, however, the main source of welfare improvement is increased level of consumption. Improvements in the distribution of consumption and leisure play a minor positive role while the decrease in leisure consumption creates a substantial negative effect on welfare.

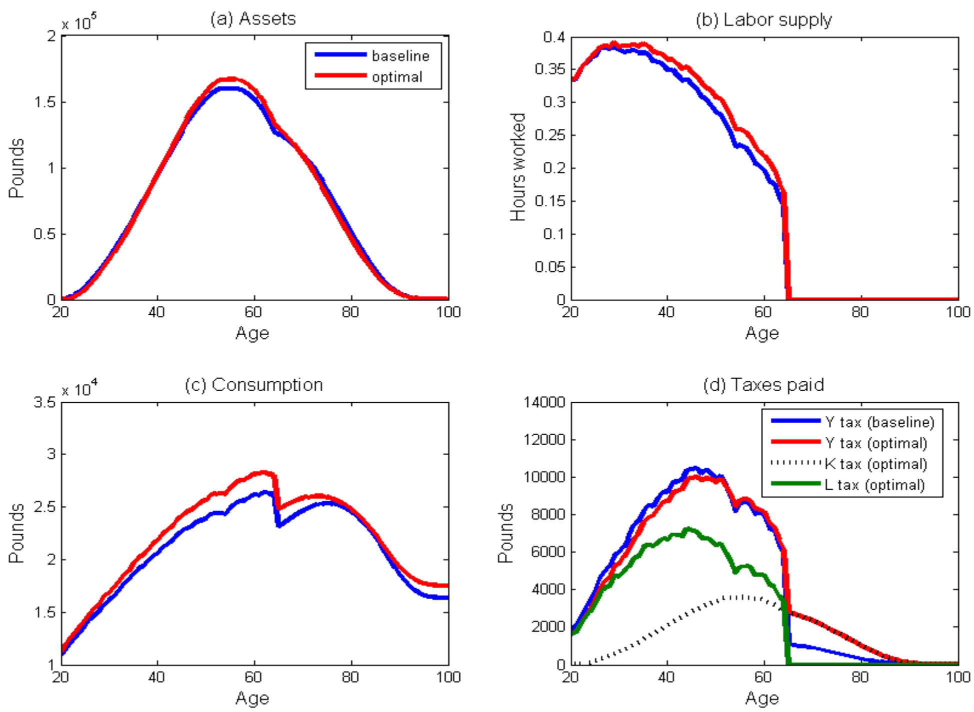

Figure 1: Life-cycle profiles of asset holdings, labor supply, consumption, and taxes paid in baseline and optimal tax economies when the taper rate is 100%

In Figure 1 we document the life-cycle profiles of the average individual type in the baseline and optimal tax system economies when the taper rate is set at 100%. The life-cycle profiles of different productivity types are given in the Appendix, Figure A3. Figure 1(a) shows the average asset holdings (the relevant tax base for the capital income tax) by age. As in earlier studies, life-cycle asset holdings are hump-shaped and individuals aged 40 to 70 bear the main burden of the capital income tax. The positive effect of the optimal tax system on asset holdings can be easily seen in the figure: At younger ages (approximately from age 20 to age 40) asset holdings are almost identical in both systems; life-cycle asset holdings in the optimal system exceed that of the base line during middle age (approximately from age 40 to 70); and the life-cycle asset holdings in the baseline system are slightly higher at old ages (approximately from age 70 to 100). This in turn reflects a significantly higher capital stock in the optimal system. While in Conesa *et al.* (2009) life-cycle asset holdings in the optimal system lie below that of the baseline, in Nakajima (2010) life-cycle asset holdings in baseline and optimal cases follow a similar path to those of Figure 1(a). The optimal tax system in our model mitigates some of the burden from the shoulders of the middle aged individuals and hence, this group's asset holdings increase.

Figure 1(b) demonstrates the average life-cycle pattern of hours worked. Labor supply increases in the early 20s up to the early 30s and declines after that until retirement age independently of the tax regime. Individuals prefer to postpone leisure to old age as a consequence of a higher time discount rate and positive after tax return on asset holdings. As it is clear from the figure, the optimal tax system results in a higher labor supply at almost all ages. This result is in contrast with that of Conesa *et al.* (2009) who find the optimal system induces individuals to work more at more productive ages.

Figure 1(c) documents the empirically plausible hump-shaped life-cycle consumption profiles for both tax systems. It also documents a discrete fall in consumption at the beginning of retirement as a result of non-separability of consumption and leisure in the utility function. As it is clear from the figure, the optimal tax system increases the level of consumption at all ages without changing the pattern much. In contrast, in Conesa *et al.* (2009), the optimal tax system smooths the distribution but decreases the level especially after retirement.

Figure 1(d) depicts the life-cycle profiles of taxes paid. Note that in the optimal system, we are able to separate the amount of taxes paid from capital and labor incomes. The life-cycle profile of tax payments tilts towards the aged in the optimal system. In the baseline case, until retirement, individuals pay more taxes. After retirement, the amount of taxes paid at each age is lower than that of the optimal tax system, which prescribes a heavier tax on capital income.

Figure A3 shows the life-cycle profiles for low (type 1) and high (type 2) ability types. From the figure we see that the optimal capital income tax system implies slightly lower asset holdings over the life-cycle for low ability types. In contrast, it positively affects high ability types' life-cycle asset holdings. In the status-quo economy, the highest marginal tax rate is 52.1%. Only high ability type individuals would face these higher rates. In the optimal system, the capital income tax rate is 34%, which is substantially lower than the marginal income tax rate in the status quo economy. As a result, high ability type individuals increase their asset holdings substantially since they receive higher after-tax return from their savings. In the benchmark economy, on the other hand, there are generous deductions for low ability type individuals. Hence, 34% tax on capital income in the optimal economy does not bring much benefit to them. Both low and high ability type individuals increase their labor supplies since they face lower marginal tax rates while the deductions are the same as in the benchmark.

The low ability type's life-cycle distribution of consumption slightly increases at every age due to an increase in labor supply. In contrast, we see a higher increase in the high ability types' life cycle consumption since the optimal system leads to a higher saving and labor supply. Figure A3(d) reveals that while the low ability type's taxes after retirement increases only slightly in the optimal case, the high ability type's taxes after retirement increases significantly.

In our model we assume away from the endogenous retirement decision. Peterman (2013b) demonstrates that the optimal capital income tax rate increases when endogenous retirement decision is taken into consideration. It seems possible that endogenous retirement could alter the relationship between the optimal tax system and the retirement program. In order to check that whether the model could be interpreted as a reduced form model capturing some of the effects of endogenous retirement, we calculate the Frisch elasticity profile for each case we considered (see figure A7 for example).[14] Our plots show that the average Frisch labor supply elasticity increases with age which is consistent with an increasing Frisch elasticity around the age that agents are considering retirement. This in turn implies that endogenous retirement may not have a large effect in our model environment. Hence, our exogenous retirement assumption seems plausible.

4.3 Effects of Means Testing

We now explore the interaction between means testing retirement income and the capital income tax. Our computational strategy is the same as above except we set the taper rate to the post-reform rate of 40% now. In the baseline case the income tax system is characterized by (κ_0, κ_1, κ_2)=$(0.521, 0.701, 0.905)$. Notice that in the baseline economies κ_2 is determined endogenously. As a natural consequence of this, κ_2 across the two baseline economies slightly differ but this small difference affects the progressivity of the tax system minimally. The optimal tax system in this setting is 34% tax rate on capital income (τ_k) and a labor income tax characterized by (κ_0, κ_1, κ_2)=$(0.457, 0.701, 0.905)$ implying the labor income tax is a flat tax with marginal rate of 45.7% and a deduction of £16698 relative to the average income of £26970.

A comparison of optimal tax systems across the two settings reveals that when the taper rate is low, a slightly higher capital income tax rate maximizes welfare. There are three reasons: First, a lower taper rate causes an increase in the government's revenue requirement (*revenue effect*). This additional revenue can be financed by an increase in labor income and/or capital income tax rates. Our results show that the additional revenue requirement is optimally financed by an increase in both labor and capital income tax rates. Second, one can interpret means-testing of retirement income as a form of non-linear capital income tax since it reduces the effective return of private retirement savings for people who are eligible for benefits relative

[14] Since all other figures are pretty similar we only provide the Frisch labor supply elasticity profile for the benchmark economy to save space. The Frisch labor supply elasticity profile is given by $\frac{1}{\sigma} - \upsilon(\frac{1}{\sigma} - 1).\frac{1-l_j}{l_j}$.

Variable	Status-quo	Optimal tax system	Change in percent
Average hours worked	0.314	0.329	4.67
Labor supply N	12.536	12.895	4.18
Capital stock K	51.129	52.298	2.23
Output Y	18.919	19.627	3.60
Consumption C	12.216	12.922	5.46
Welfare			Change in percent
CEV			1.51
CEV_C			5.73
CEV_{CL}			5.46
CEV_{CD}			0.27
CEV_L			-4.22
CEV_{LL}			-4.67
CEV_{LD}			0.45
Income Tax System			
τ_k		0.34	
κ_0	0.521	0.457	
κ_1	0.701	0.701	
κ_2	0.905	0.905	

Table 3: Economic aggregates and social welfare in status-quo (baseline) and optimal tax system economies when the taper rate is 40%

to those who are not (*substitution effect*). When the taper rate is reduced, the effective tax on capital income decreases. This in turn implies a higher optimal capital income tax rate as well. Third, the optimal tax on capital increases when the size of the means-tested pension program increases as a result of a decrease in the taper rate (*pension benefit effect*). Revenue and pension benefit effects are somehow related. Lower taper rates imply that more individuals receive more generous means-tested benefits. Hence, the government needs to increase taxes on capital and labor incomes to fulfill its revenue requirement. Since retired individuals now get higher benefits, the government would prefer to tax capital income more to unwind some of generous retirement benefits.

Table 3 presents equilibrium statistics of the baseline and optimal tax systems and welfare consequences of switching from the baseline tax system to the optimal one. Similar to the benchmark case all economic aggregates grow. Yet, the growth rates of economic aggregates are larger in this setting. This implies that when the taper rate is low, switching from the baseline tax system to the optimal tax system creates a larger improvement in economic aggregates. We see a similar trend in the welfare measure as well. In an economy with a lower taper rate, the optimal tax system increases welfare relatively more. The intuition is as follows. When the taper rate is high, the effective tax on capital income is relatively closer to its optimal value but when the taper rate is low the effective tax on capital income is relatively far away from the optimal value. Hence, the optimal tax system prescribes a higher capital income tax rate and improves welfare more when the taper rate is low. This result is important in the following sense. When the taper rate is low, the need for switching the tax system from the baseline to the optimal one is quite crucial. Yet, when the taper rate is high, the need for reform in the tax system is relatively less crucial.

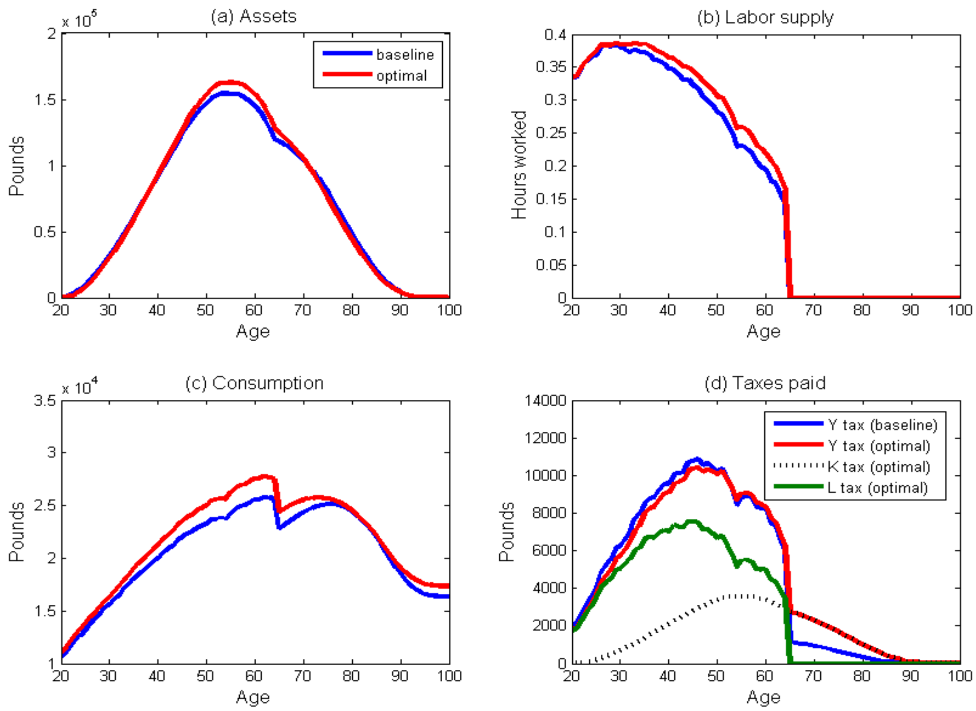

Figure 2: Life-cycle profiles of asset holdings, labor supply, consumption, and taxes paid in baseline and optimal tax economies when the taper rate is 40%

Figure 2 documents the life-cycle profiles of the average individual type in the baseline and optimal tax system economies when the taper rate is 40%. We report the life-cycle profiles of different productivity types in the Appendix, Figure A4. A comparison of Figures 1 and 2 reveals that the optimal tax systems in the two settings create similar distributional effects on the life-cycle profiles. Low and high ability types' life-cycle profiles also do not much differ across two settings.

Now we go further and reduce the taper to zero. This is equivalent to a universal pension program since all individuals receive the benefits without any reduction. In the baseline case the income tax system is characterized by (κ_0, κ_1, κ_2)=$(0.521, 0.701, 1.427)$. The optimal tax system in this case is a 37% tax rate on capital income (τ_k) and a labor income tax characterized by (κ_0, κ_1, κ_2)=$(0.465, 0.701, 1.427)$ implying the labor income tax is a flat tax with marginal rate of 46.5% and a deduction of £13318 relative to the average income of £26970. Our aforementioned claims regarding the relationship between means-testing and the optimal capital income tax rate is further strengthened here: When the taper rate is low, the optimal capital income tax rate is relatively higher. Zero taper rate means a form of non-linear tax on capital income at older ages is absent. Hence, the capital income tax must be higher to allow the overall effective tax on capital income to reach its optimal value, in addition to the higher revenue financing requirements.

Variable	Status-quo	Optimal tax system	Change in percent
Average hours worked	0.307	0.324	5.34
Labor supply N	12.109	12.705	4.69
Capital stock K	43.933	46.909	6.24
Output Y	17.825	18.800	5.19
Consumption C	10.974	11.842	7.33
Welfare			Change in percent
CEV			3.47
CEV_C			7.93
CEV_{CL}			7.33
CEV_{CD}			0.60
CEV_L			-4.46
CEV_{LL}			-5.34
CEV_{LD}			0.88
Income Tax System			
τ_k		0.37	
κ_0	0.521	0.465	
κ_1	0.701	0.701	
κ_2	1.427	1.427	

Table 4: Economic aggregates and social welfare in status-quo (baseline) and optimal tax system economies when the taper rate is 0%

Table 4 presents equilibrium statistics of the baseline and optimal tax systems and welfare consequences of switching from the baseline tax system to the optimal one. A zero taper rate specification implies an overall effective tax structure with no separate capital taxation, so the potential for welfare improvement from the optimal capital tax system is much greater. This specification effectively removes one capital tax instrument, so that the conventional capital income tax now carries the full weight of generating welfare and aggregate improvements. Similar to the earlier settings all economic aggregates grow, but the rates of growth are significantly larger in this setting. We see a similar trend in the welfare measure as well. Welfare improvement is much higher than the previous settings. The significant level effect is also reflected in CEV_{CL} measure which is significantly higher than the previous ones. Figures A1 and A5 in Appendix report the figures of life-cycle profiles for average type and low and high ability types respectively. The pattern of life-cycle profiles do not differ much from those of the previous settings.

Our results in this setting have an important policy implication: In an economy with an universal pension program financed through the general budget, reforming the tax system can generate a substantial welfare improvement.

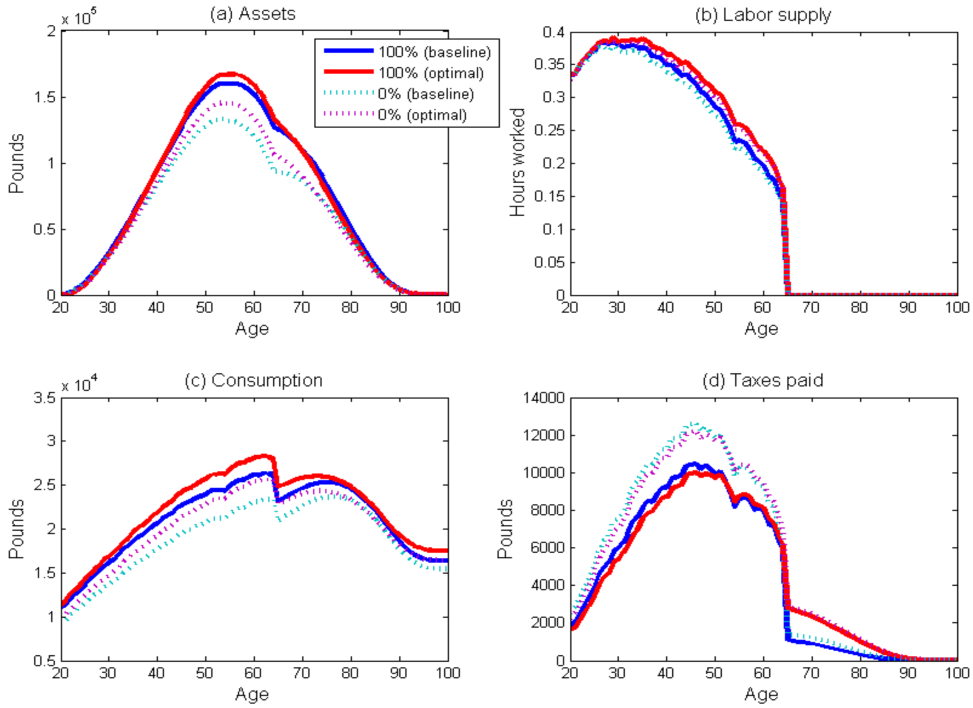

Figure 3: Comparison of life-cycle profiles of asset holdings, labor supply, consumption, and taxes paid in baseline and optimal tax economies when the taper rates are 100% and 0%

Figure 3 presents the life-cycle profiles of the settings with zero and 100% taper rates in the baseline and optimal tax systems. The overall effective tax systems differ between the two settings, because in one case, we specify an effective age based capital income tax, and then choose an optimal capital tax, while in the other, no pre-existing age based tax is specified. But the figure reveals the quasi complementarity between these two cases, and the implicit partial substitutability between the means test and a capital tax. More precisely, the asset distribution in the economy with a zero taper rate and a baseline tax system can be improved by either switching from the baseline tax system to the optimal one keeping the taper rate intact, or switching from a zero taper rate to a 100% taper rate keeping the baseline tax system intact. While these policies are distinct, their quasi-complementarity is clearly demonstrated here. Flexibility in choosing a non-zero taper rate enhances the government's choice set.

Finally, we analyze the economy with no means tested pension program. Only the earnings-related pension now exists. This implies a lower revenue requirement. In the baseline case the income tax system is characterized by (κ_0, κ_1, κ_2)=$(0.521, 0.701, 0.691)$. The optimal tax system in this case is 31% tax rate on capital income (τ_k) and a labor income tax characterized by (κ_0, κ_1, κ_2)=$(0.437, 0.701, 0.691)$ implying the labor income tax is a flat tax with marginal rate of 43.7% and a deduction of £18532 relative to the average income of £26970.

This setting may be compared with our earlier specifications in two dimensions. In terms of revenue requirement, it is closer to the 100% taper specification but in terms of the profile of tax rates, it is closer to the zero taper specification i.e. there is only one type of tax

Variable	Status-quo	Optimal tax system	Change in percent
Average hours worked	0.323	0.337	4.03
Labor supply N	12.969	13.219	3.95
Capital stock K	55.878	57.384	2.62
Output Y	19.804	20.534	3.56
Consumption C	13.074	13.888	5.87
Welfare			Change in pecent
CEV			1.67
CEV_C			6.13
CEV_{CL}			5.87
CEV_{CD}			0.26
CEV_L			-4.46
CEV_{LL}			-4.03
CEV_{LD}			-0.43
Income Tax System			
τ_k		0.31	
κ_0	0.521	0.437	
κ_1	0.701	0.701	
κ_2	0.691	0.691	

Table 5: Economic aggregates and social welfare in status-quo (baseline) and optimal tax system economies when the means-tested pension program is removed

on capital income. Because the government's revenue requirement is relatively lower in this setting, optimal tax rates on labor and capital incomes are lower than those of the previous settings. This in turn implies that the welfare improvement from realigning taxes is less than that of the zero-taper rate setting.

On the other hand, an economic setting with a higher-taper-rate means-tested pension program yields a resource allocation pattern where the potential for welfare improvement is less. More precisely, the optimal tax system generates the largest welfare improvement when the taper rate is zero, the second largest welfare improvement when there is no means tested program, the third largest welfare improvement when the taper rate is 40% and the lowest welfare improvement when the taper rate is 100%. This result is interesting in a sense that it highlights the complementarity between optimal income tax rate and taper rate once again: Although the existence of a means-tested pension program increases the government's revenue requirement and puts upward pressure on both optimal capital and labor income tax rates, its positive effect on life-cycle asset holdings significantly reduces the potential welfare gains from the tax reform.

Figures A2 and A6 in the Appendix report the life-cycle profiles for average type individuals and low and high ability types, respectively. The pattern of life-cycle profiles do not differ much from those of the earlier settings.

As we mentioned earlier our results reveal three effects: *revenue*, *substitution*, and *pension benefit*. In order to isolate these effects we conduct two counter-factuals. In the first counter-

100% Taper Rate			
Tax rates	Lower Benefits	Higher Benefits	No Revenue Effect
κ_0	45.4%	36.5%	39.3%
τ_k	33%	38%	0%
40% Taper Rate			
	Lower Benefits	Higher Benefits	No Revenue Effect
κ_0	45.7%	41%	36.5%
τ_k	34%	41%	6%
0% Taper Rate			
	Lower Benefits	Higher Benefits	No Revenue Effect
κ_0	46.5%	62.8%	35.7%
τ_k	37%	42%	8%

Table 6: Tax rates

factual, we increased the maximum amount of means-tested pension benefits ($\overline{b_t}$) by setting it to 10% of output per capita. We call this counter-factual as "higher benefit model." In the second counter-factual, we assume that no revenue is required to finance means-tested pension programs. In this exercise $\overline{b_t}$ did not change. We call this counter-factual as "no revenue model." Table 6 shows the tax rates in main, higher benefit and no revenue models.

First we analyze what would happen if we increase $\overline{b_t}$ for a given taper rate by comparing the main model with the higher benefit model. Since the taper rate is kept constant, the substitution effect has no role in this exercise. When we increase $\overline{b_t}$, we observe optimal capital tax rates in the higher benefit model is much larger than those in the main model for each taper rate. When taper rate is 100%, increasing $\overline{b_t}$ caused a 15% increase in the capital income tax rate. When taper rate is 40%, increasing $\overline{b_t}$ caused a 20% increase in the capital income tax rate. These results demonstrate that both revenue and pension benefit effects are quite significant. The intuition for the revenue effect is straightforward. Higher pension benefits require higher revenue to finance those benefits for each taper rate and hence, tax on capital income increases. The intuition for pension benefit effect is as follows: The social planner chooses a lower capital tax when pension benefits are smaller. This way the social planner can replace some of the lower post retirement income from smaller pension benefits by increasing the annual after-tax return on savings by lowering tax on capital income. Table 8 shows the changes in aggregate economies and welfare across status quo and optimal economies when $\overline{b_t}$ is increased.[15]

Second, we analyze what would happen if we ignore the revenue requirements by comparing the main model with the no revenue model. Optimal capital income tax rates become substantially lower for all taper rates we considered. Since $\overline{b_t}$ are kept at the same rate across two models, pension benefit and substitution effects have no roles in this comparison. When the taper rate is 40%, the optimal capital income tax rate decreases by 82.35% if remove the

[15] The intuition behind results are similar to those given earlier.

revenue requirement. Similarly, when the taper rate is 0%, the optimal capital income tax rate decreases by 78.38%. Thus, we can claim that the revenue effect is quite significant and play an important role to determine how high the optimal capital tax rate will be.

Third, we analyze the role of the substitution effect by comparing the optimal capital income tax rates for each taper rate in the no revenue effect model. In this comparison, the revenue effect has no role. The pension benefit effect would have a role since lower taper rates imply generous pension benefits. When we increase the taper rate from 0% to 40%, the optimal capital income tax rate decreases by 33.33%. Similarly, when we increase the taper rate from 40% to 100%, the optimal capital income tax rate decreases by 100%. Intuition is as follows: Increasing the taper rate, decreases the need for capital income tax rate since the higher taper rates act as a non-linear tax on after retirement income and substitutes capital income tax (substitution effect). When we increase the taper rate, we decrease both the number of individuals who receive means-tested benefits and the amount of pension benefit entitlements. Hence, the social planner chooses a lower capital tax when pension benefits are smaller (pension benefit effect). In sum, all three effects play a significant role in determining how big the optimal capital tax rate would be. Table 9 displays the changes in aggregate economies and welfare across status quo and optimal economies when benefits are increased.[16]

In a different model setting, Sefton & van de Ven (2009) analyze the implications of various tax reforms in the presence of means-testing without searching for the optimal tax system. Our analysis differs not only form the modelling perspective as explained earlier, but also differs in solving for the optimal tax system a lá Conesa *et al.* (2009) and establishing the degree of complementarity between the capital income tax and means-testing.

Our paper is also related with the recent literature that extends Conesa *et al.* (2009) in various directions to investigate the determinants of the higher optimal capital income tax rate. Peterman (2013a) highlights the impact of changing two assumptions: variable Frisch elasticity of labor supply and taxing accidental bequests at the same rate. These changes cause the optimal tax on capital to drop by almost half. Nakajima (2010) incorporates a housing asset into a model similar to that of Conesa *et al.* (2009) and shows that the optimal capital income tax rate in the model with housing is 1%. Kuklik (2011) extends Conesa *et al.* (2009)'s model by adding two additional elements: a non-linear mapping between hours worked and wages and inter-vivos transfers and shows that the optimal capital income tax rate in the US is 7.4%. Peterman (2013b) and Peterman (2015) show that incorporating endogenous retirement decision and learning by doing also cause increases in optimal capital tax rates. Incorporating the transition path from the status quo to the reformed steady state can also matter for the optimal capital tax rate. Fehr & Kindermann (2015) show that the optimal capital tax rate is significantly lower when transitional cohorts explicitly taken into account. Our model, although it is not calibrated to the US economy, shares many common features with that of Conesa *et al.* In particular, our setting with no-means-tested pension program is quite similar to their benchmark model. Our results demonstrate another channel that affects optimal capital income

[16] The intuition behind results are similar to those given earlier.

tax rates: a social insurance program that is financed from the general budget.

Finally, our results suggest not just that positive capital income taxation may be welfare improving, but that means testing publicly financed retirement pensions has a similar impact. Means testing may not only reduce the revenue requirement for a given pension benefit, but improve resource allocation and aggregate welfare. This is of special interest in light of current global debate on public pension reform and taxation.

5 Conclusion

In this paper we study the interaction between capital income taxation and means tested retirement transfer in the context of an overlapping generations model, calibrated to the UK economy. Recent literature has suggested a rehabilitation of capital income taxation (Conesa *et al.* (2009)), predicated on the idea that tax on capital income would be a partial substitute for the optimal age-based taxes when they are infeasible. This leads naturally to the conjecture that a publicly funded age pension contingent upon holdings of capital or capital income may have a similar effect.

We extend Conesa *et al.* (2009)'s canonical framework by explicitly incorporating means testing into the public retirement transfer system, so that we can analyze the interactions between means testing and capital income taxation. Within the broad framework of an incomplete market stochastic general equilibrium OLG model, calibrated to the UK economy, we specify a suite of model settings which allow us to study the impacts of alternative taper rates of the transfer system on the optimal capital and labour income tax rates. We hypothesize that because a taper rate operates as a de facto capital income tax rate on retirement assets, the optimal capital income tax rate will be lower, the higher the taper rate. Further, the taper rate directly impacts retirement assets, rather than capital as it accumulates throughout the life cycle, and this extended structure allows us to explore the implications of this age-based policy.

Our results confirm those of recent studies suggesting that a significantly positive capital income tax rate may be optimal. In our model, the largest source of welfare improvement is the increase in the level of aggregate consumption as a flowing from the optimal tax system.

More importantly, we show that there is a negative relation between taper rates and the optimal capital income tax rate: the higher the benefit reduction rate, the lower the optimal capital income tax rate. The intuition is as follows: First, a higher taper rate implies a lower revenue requirement. This in turn implies lower optimal capital and labor income tax rates. Second, the means-tested pension program acts as a non-linear capital income tax by only targeting individuals over the retirement age. Thus, when the taper rate is higher, the optimal capital income tax rate becomes relatively lower. Third, the optimal tax on capital increases when the size of the retirement program increases to unwind some of generous retirement benefits.

Interestingly, when the taper rate is 100%, the welfare improvement as a result of changing the tax system from the baseline to the optimal one generates the lowest welfare gain among all the settings we considered. This result further highlights the role of a means-tested pension program as an effective way of targeting capital income. It has also been shown that a similar pattern of life-cycle asset holdings can be generated by either reforming the baseline tax system or changing the taper rate. From this perspective, the existence of a means-tested pension program in the economy enhances the policy maker's options.

Appendix

Solution Algorithm

1. Fix the taper rate (ϕ). In the baseline tax economies set the values of κ_0 and κ_1 to their estimated values. The value of κ_2 is adjusted along with the prices. In the optimal tax economies, first create a grid for τ_k. In each loop, set the values of κ_1 and κ_2 to their corresponding baseline tax economy (economy with the same taper rate) values. Let κ_0 (marginal tax rate on labor income) is determined endogenously such that the total tax revenue in the baseline and optimal tax economies are the same.

2. Guess prices r, w, amount of lump-sum transfer η, and the PAYG replacement rate θ in both economies. In the baseline tax economy, guess the value of κ_2. In the optimal tax economy guess the value of κ_0.

3. In the baseline tax economy, for given $(\phi, r, w, \eta, \theta, \kappa_2)$, solve the individual's maximization problem by the backward induction and calculate the optimal decision rules for consumption, asset holdings, and labor supply. In the optimal tax economy, for given $(\phi, \tau_k, r, w, \eta, \theta, \kappa_0)$, solve the individual's maximization problem by backward induction and the calculate the optimal decision rules.

4. After obtaining the optimal decision rules, calculate the distribution of individuals through forward recursion.

5. By using the results in step 4, compute the aggregate variables.

6. Use the aggregate variables calculated in step 5 to construct new guesses for the variables in step 2.

7. Compare the old and new guess values. If the distance between old and new guess values are smaller then the pre-determined tolerance value, an equilibrium is found. Otherwise update the guess values and go to step 3.

8. For the optimal tax economy, calculate the equilibrium values for each value of τ_k. Call the equilibrium that generates the largest social welfare the optimal tax equilibrium.

Gouveia-Strauss Tax Function

We use the information regarding income tax rates and allowances for 2010/11 published by the HM Revenue and Customs to generate a data consists of income and corresponding income tax rates. By using this data we estimated the parameter values of the Gouveia-Strauss tax function for the UK economy. The parameters of the Gouveia-Strauss tax function is estimated by weighted non-linear least squares. Table 7 displays the estimated parameter values of the Gouveia-Strauss tax function. Figure A0 displays the shape of the average tax rates.

κ_0	κ_1	κ_2
.521*	.701*	.318*
(.0008)	(.0048)	(.0006)

*Significant at 1% level
Standard deviations are in parantheses

Table 7: Tax Function Parameter Estimates

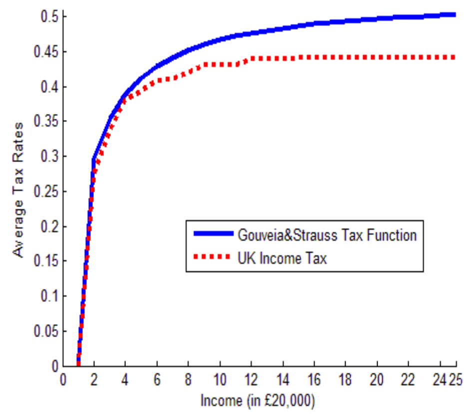

Figure A0: Average income tax rates generated by the Gouveia-Strauss tax function vs. average income tax rates calculated by using the data, which is generated by employing the information on tax rates and allowances for 2010/11 published by HM Revenue and Customs.

Figures & Tables

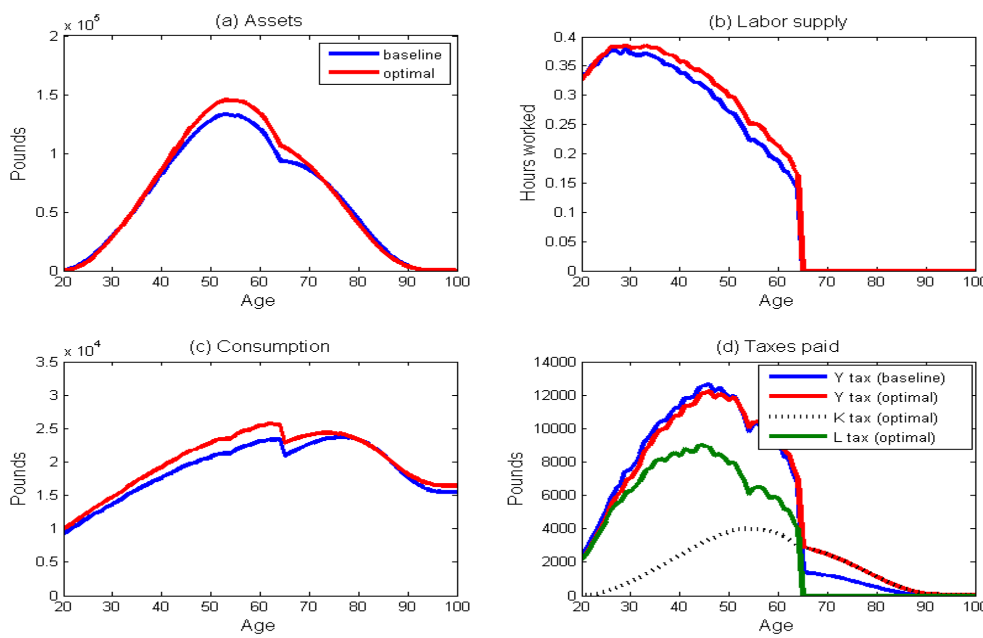

Figure A1: Life-cycle profiles of asset holdings, labor supply, consumption, and taxes paid in baseline and optimal tax economies when the taper rate is 0%

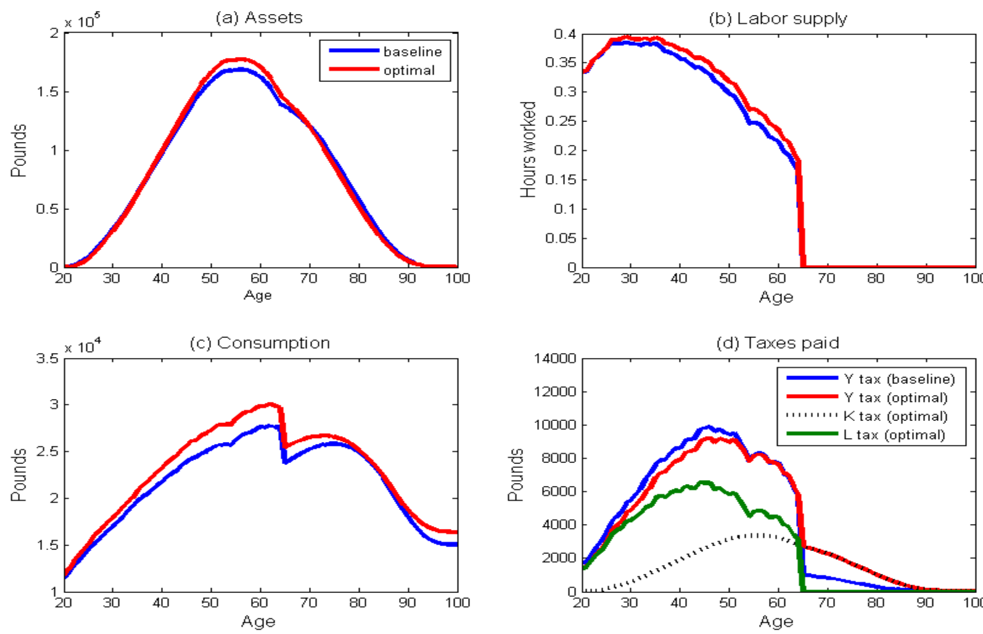

Figure A2: Life-cycle profiles of asset holdings, labor supply, consumption, and taxes paid in baseline and optimal tax economies when there is no means-tested pension program

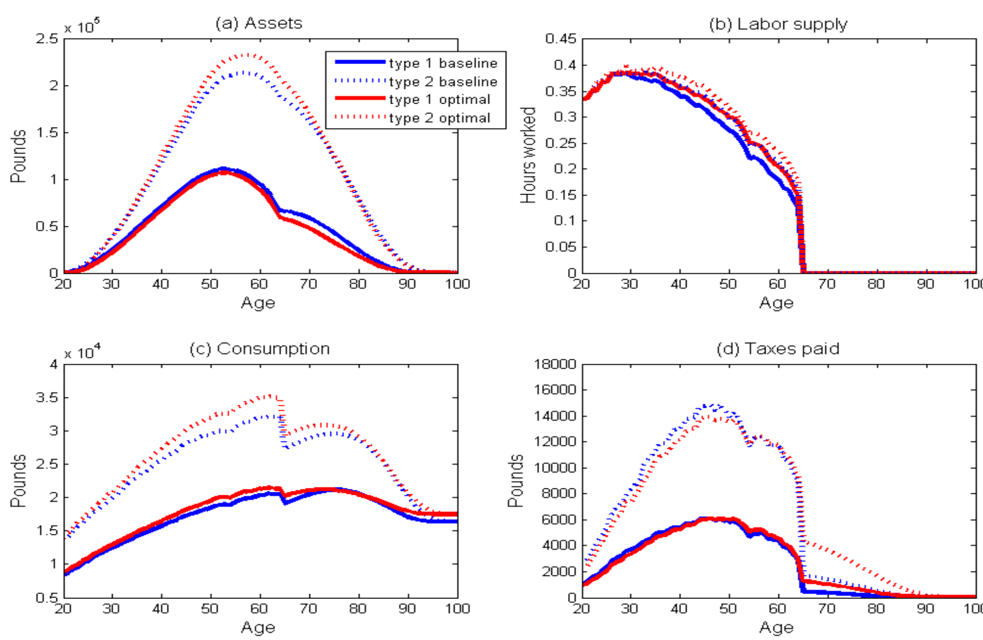

Figure A3: Life-cycle profiles of asset holdings, labor supply, consumption, and taxes paid in baseline and optimal tax economies for types 1 and 2 when the taper rate is 100%

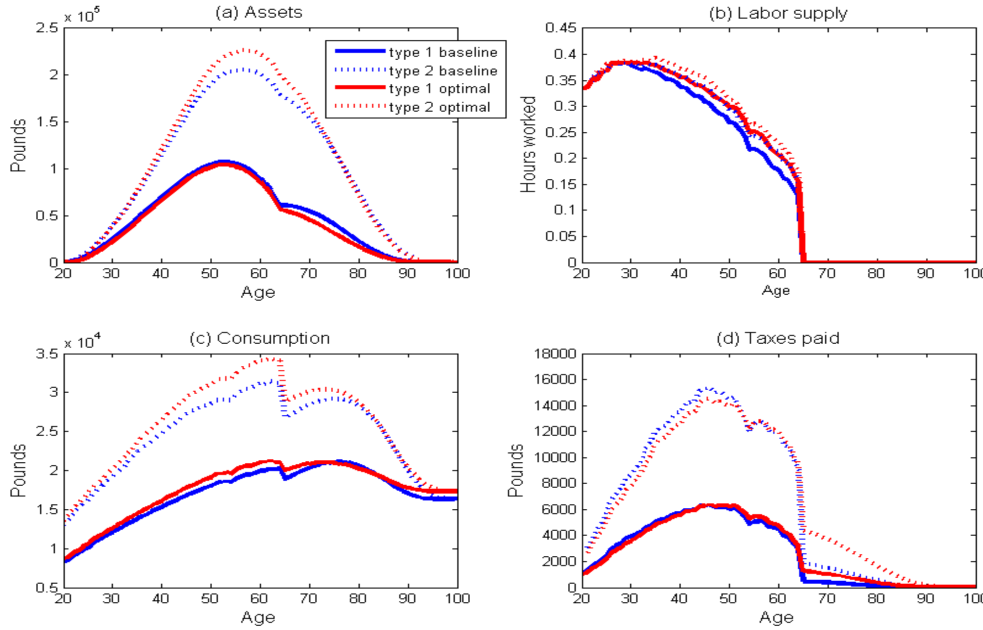

Figure A4: Life-cycle profiles of asset holdings, labor supply, consumption, and taxes paid in baseline and optimal tax economies for types 1 and 2 when the taper rate is 40%

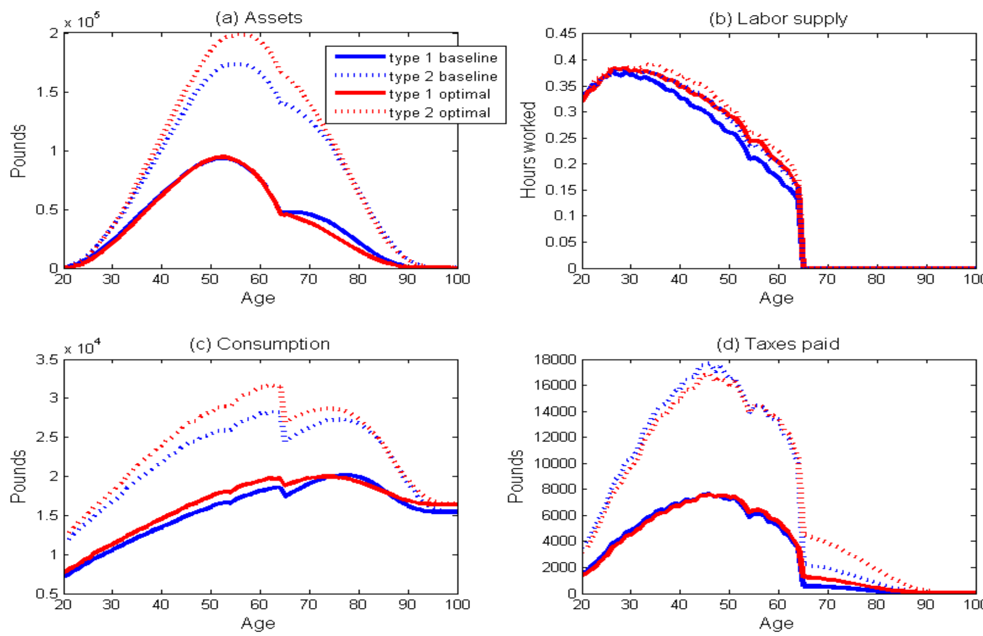

Figure A5: Life-cycle profiles of asset holdings, labor supply, consumption, and taxes paid in baseline and optimal tax economies for types 1 and 2 when the taper rate is 0%

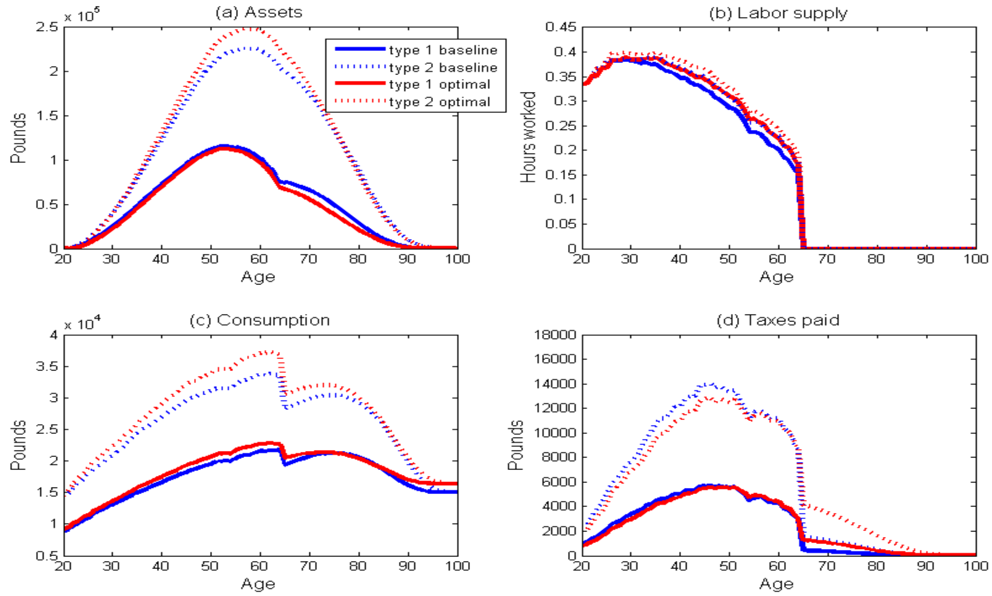

Figure A6: Life-cycle profiles of asset holdings, labor supply, consumption, and taxes paid in baseline and optimal tax economies for types 1 and 2 when there is no means-tested pension program

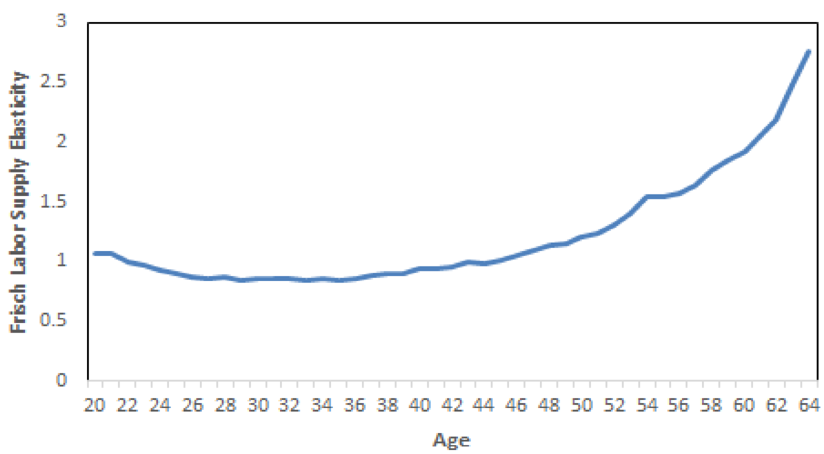

Figure A7: Frisch elasticity of labor supply in the benchmark economy

100% Taper			
Variable	Status-quo	Optimal tax system	Change in percent
Average hours worked	0.333	0.345	3.28
Labor supply N	13.700	14.203	3.54
Capital stock K	52.797	50.974	-3.57
Output Y	20.535	20.839	1.46
Consumption C	14.543	15.396	5.54
Welfare (CEV)			1.32
40% Taper			
Variable	Status-quo	Optimal tax system	Change in percent
Average hours worked	0.326	0.342	4.69
Labor supply N	13.474	14.038	4.02
Capital stock K	47.078	46.978	-0.21
Output Y	19.611	20.169	2.77
Consumption C	13.387	14.632	8.51
Welfare (CEV)			4.90
0% Taper			
Variable	Status-quo	Optimal tax system	Change in percent
Average hours worked	0.319	0.330	3.43
Labor supply N	13.229	13.382	1.14
Capital stock K	37.205	40.708	8.61
Output Y	18.040	18.684	3.44
Consumption C	11.845	12.517	5.37
Welfare (CEV)			7.98

Table 8: Economic aggregates and social welfare in status-quo (baseline) and optimal tax system economies when the maximum amount of pension entitlements doubled

100% Taper			
Variable	Status-quo	Optimal tax system	Change in percent
Average hours worked	0.352	0.348	-1
Labor supply N	14.342	14.314	-0.20
Capital stock K	65.331	71.690	8.87
Output Y	22.603	23.210	2.62
Consumption C	16.780	17.427	3.71
Welfare (CEV)			0.92
40% Taper			
Variable	Status-quo	Optimal tax system	Change in percent
Average hours worked	0.3496	0.3498	0.04
Labor supply N	14.274	14.377	0.72
Capital stock K	64.914	69.687	6.85
Output Y	22.485	23.084	2.60
Consumption C	16.744	17.466	4.14
Welfare (CEV)			0.79
0% Taper			
Variable	Status-quo	Optimal tax system	Change in percent
Average hours worked	0.351	0.352	0.5
Labor supply N	14.256	14.426	1.18
Capital stock K	63.099	67.564	6.61
Output Y	22.274	22.925	2.84
Consumption C	16.921	17.679	4.28
Welfare (CEV)			0.66

Table 9: Economic aggregates and social welfare in status-quo (baseline) and optimal tax system economies when the substitution effect isolated

References

Auerbach, A. J., & Kotlikoff, L. J. 1987. *Dynamic Fiscal Policy*. New York, NY, USA: Cambridge University Press.

Batini, N., Jackson, B., & Nickell, S. 2000. Inflation Dynamics and the Labour Share in the UK. *Bank of England Discussion Paper*.

Blundell, R., & Etheridge, B. 2008. Consumption, Income and Earnings Inequality in the UK. *Working Paper*.

Castañeda, Ana, Díaz-giménez, Javier, & víctor Ríos-rull, José. 1998. Earnings and wealth inequality and income taxation: Quantifying the trade-offs of switching the U.S. to a proportional income tax system. *Mimeo*.

Chamley, C. 1986. Optimal taxation of capital income in general equilibrium with infinite lives. *Econometrica*, **54**, 607–622.

Conesa, J. C., & Krueger, D. 2006. On the Optimal Progressivity of the Income Tax Code. *Journal of Monetary*, **53**, 1425–1450.

Conesa, J. C., Kitao, S., & Krueger, D. 2009. Taxing capital? Not a bad idea after all! *American Economic Review*, **99**, 25–48.

Doblin, Claire P. 1991. Capital Stock and Capital Output Ratios: A Comparison Between the United States, United Kingdom and the Federal Republic of Germany. *International Institute for Applied Systems Analysis Working Paper*, **WP-91-29**.

Fehr, Hans, & Kindermann, Fabian. 2015. Taxing Capital Along the Transition-Not a bad idea after all? *Journal of Economic Dynamics and Control*, **51**, 64–77.

Fukushima, Kenichi. 2010. Quantifying the Welfare Gains From Flexible Dynamic Income Tax Systems. *Working Paper*.

Gervais, Martin. 2012. On the Optimaity of Age-Dependent Taxes and the Progressive US Tax System. *Journal of Economic Dynamics and Control*, **36**, 682–691.

Golosov, Mikhail, & Tsyvinski, Aleh. 2006. Designing Optimal Disability Insurance: A Case for Asset Testing. *Journal of Political Economy*, **114**, 257–279.

Gouveia, M., & Strauss, R. 1994. Effective Federal Individual Income Tax Functions: An Exploratory Empirical Analysis. *National Tax Journal*, **47**, 317–339.

Guvenen, Fatih, Karahan, Fatih, Ozkan, Serdar, & Song, Jae. 2015. What Do Data on Millions of U.S. Workers Reveal about Life-Cycle Earnings Risk? *Working Paper*.

Judd, Kenneth L. 1985. REDISTRIBUTIVE TAXATION IN A SIMPLE PERFECT FORESIGHT MODEL. *Journal of Public Economics*, **28**, 59–83.

Kaygusuz, Remzi. 2015. Social Security and Two Earner Households. *Journal of Economic Dynamics and Control*.

Kitao, Sagiri. 2010. Labor-dependent Capital Income Taxation. *Journal of Monetary Economics*, **57**, 959–974.

Kitao, Sagiri. 2014. Sustainable Social Security: Four Options. *Review of Econoic Dynamics*.

Kuklik, Michael. 2011. Optimal Taxation and Labor Supply. *Working Paper*.

Kumru, Cagri S, & Piggott, John. 2009. Should Public Retirement Provision Be Means-tested? *Australian School of Business Research Paper No. 2009 AIPAR 01*.

Nakajima, Makoto. 2010. Optimal Capital Income Taxation with Housing. *Working Paper*.

National Statistics. 2009a. *Population Change: UK population increases by 388000*. <http://www.statistics.gov.uk/CCI/nugget.asp?ID=950&Pos=5&ColRank=2&Rank=1000>.

National Statistics. 2009b. *United Kingdom Interim Life Tables 1980-82 to 2005-07*. <http://www.statistics.gov.uk/StatBase/Product.asp?vlnk=14459&Pos=&ColRank=1&Rank=422>.

Peterman, William. 2013a. Determining the Motives for a Positive Optimal Tax on Capital. *Journal of Economic Dynamics and Control*, **37**, 265–295.

Peterman, William. 2013b. An Extensive Look at Taxes: How Does Endogenous Retirement Affect Optimal Taxation? *Working Paper*.

Peterman, William. 2015. The Effect of Endogenous Human Capital Accumulation on Optimal Taxation. *Working Paper*.

Robinson, H. 2003. Are you experienced? British evidence on age-earnings profiles. *Applied Economics*, **35**, 1101–1115.

Rull, Jose-Victor Rios. 1999. *Computational Methods for the Study of Economic Dynamics*. Oxford University Press.

Sefton, J., van de Ven, J., & Weale, M. 2008. Means testing retirement benefits: Fostering Equity or Discouraging Savings? *Economic Journal*, **118**, 556–590.

Sefton, James, & van de Ven, Justin. 2009. Optimal Design of Means Tested Retirement Benefits. *Economic Journal*, **119**, 461–481.

Shourideh, Ali, & Troshkin, Maxim. 2012. Providing Efficient Incentives to Work: Retirement Ages and the Pension System. *Working Paper*.

Weale, M. 2004. *UK Productivity: its failings and outlook*. Presented by Martin Weale, CBE, Director, NIESR at the Society of Business Economists Annual Conference.