THE MACROECONOMIC EFFECTS OF ENDOGENOUS LIFE EXPECTANCY

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Abstract

This thesis provides three general equilibrium overlapping generations models to analyze the macroeconomic effects of endogenous life expectancy. I find that endogenous life expectancy has substantial effects on the effective discount rate, the demographic structure of the economy and productivity through the health channel, which subsquently affect human and physical capital accumulation, welfare and fiscal policy.

In Chapter 1, I study the presence and magnitude of macroeconomic externalities associated with obesity. I argue that focusing solely on the economic costs on health care spending ignores the effects of obesity on net social security benefits caused by higher mortality among obese individuals. To estimate the size of this externality, I develop an overlapping generations model with rational choice with respect to food consumption and weight as in Lakdawalla and Philipson (2009), endogeneizing life expectancy, labour productivity and health care costs. The life-time net contributions of the top 30% of the BMI distribution are negative but quantitatively small, despite the fact that the model generates substantial wealth and income inequality, consistent with the observed socioeconomic gradient of obesity (Baum and Ruhm, 2009), which results in lower lifetime contributions. Furthermore, I perform two policy experiments (i) eliminating childhood obesity and (ii) eliminating the VAT exemption of food consumption, both resulting in significant welfare gains, with the former eliminating the obesity externality.

In Chapter 2, I study the effects of health on optimal taxation, where health affects the level of utility, the probability of survival and productivity. The results suggest that health affects optimal taxation in the Ramsey problem via three channels. First, since health is a stock that naturally deteriorates over time, the optimal level of taxation of medical spending is not constant over the life-cycle. Second, the productivity-enhancing aspect of health affects labour supply decisions over the life-cycle, where it is optimal for the government to use age-dependent labour income taxes to minimize distortions in the labour market. If the government cannot condition health care spending and labour income taxes on age, then a non-zero capital income tax can be implemented to achieve the optimal allocation. Finally, productivity growth in the medical sector which directly or indirectly affects longevity has a heterogeneous effect on each cohort, which in the absence of age-dependent taxation creates an evolutionary path of the optimal capital income taxation.

In Chapter 3, I examine the macroeconomic effects of an increase in the retirement age as a response to an ageing population and deteriorating dependency ratios. An increase in retirement age induces agents to increase medical spending. Households invest in their level of health in order to be fit to work for longer, since older agents that are affected by the retirement age reform have a lower level of health and increased working hours lost due to illness. Furthermore, the higher level of health raises life expectancy, partially offsetting the effects of the retirement age reform with respect to dependency ratios.

Declaration

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Chapter 1

Introduction

Since the seminal papers by Samuelson (1958) and Diamond (1965), Overlapping Generations models (OLG) have become the one of the two main workhorses in macroeconomics, the other being the Ramsey–Cass–Koopmans model where agents have infinite life-times and no new agents enter the economy.

The importance of OLG models cannot be overstated for two reasons; first, the life-cycle aspect of OLG models reveals that the convenient welfare properties of the Ramsey–Cass– Koopmans models are a special case and they can fail even if we assume perfect Arrow-Debreu markets in OLG models. This gave rise to an extensive literature that studied whether economies are actually inefficient (Abel et al., 1989), and policies that could improve the efficiency of the economy such as unfunded social security schemes (Hubbard and Judd, 1987) and government debt (Diamond (1965) and Barro (1974)). Second, the OLG framework is the natural framework to study economies where the individuals' life-cycle plays a prominent role in shaping the economic environment such as pensions (Feldstein, 1985), dynamic fiscal policy (Auerbach and Kotlikoff, 1987), taxation (Mateos-Planas, 2010), fertility (Becker and Barro, 1988) and human capital accumulation (Glomm and Ravikumar, 1992).

According to Weil (2008), these properties arise from the fact that new agents enter the economy in every period and "[h]ow and when consumers vanish is, for the economist who wants to understand why the overlapping generations model is different, of secondary interest". This view, combined with the peculiarities of endogenous mortality resulted in mortality being neglected in the macroeconomic literature and the subsequent literature of "perpetual youth models" where life expectancy is stochastic. However, mortality is treated as exogenous in these models.. As Rossen (1988) points out, endogeneizing mortality poses a series of challenges which economists need to tackle. First, with endogenous mortality the level of utility matters for the optimal decision of the household in contrast to the standard models in the literature where only marginal utility matters. Hence standard functional forms for the utility function which are negative in levels (e.g. the CRRA utility function) have the wrong shape and agents cannot maximize utility. Second, with the standard preference specification, the marginal utility from consumption is non-constant which has important policy implications.

However, studying the macroeconomics effects of changes in longevity, namely how and when agents exit the economy, has become a pressing issue for most countries since life expectancy is increasing over time. This affects the demographic structure of the economy, with subsequent effects on social security, health care spending, human and capital accumulation, fiscal policy and growth. Life expectancy has been studied in the literature using the framework of Blanchard (1985) and more recently by Cervellati and Sunde (2005); De Nardi, French and Jones (2009, 2010); Cervellati and Sunde (2011), but the in an exogenous, stochastic setting. The influential paper by Hall and Jones (2007) who study the rise in health care spending in the US during the last decades, drew attention to the important macroeconomic implications of endogenous life expectancy (see inter alia Bhattacharya and Qiao (2007), Zhao (2014) and Halliday et al. (2017))[1].

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[1] Hall and Jones (2007) tackle the issue of the negative level of utility by adding a constant parameter in the utility function, which is large enough in order to ensure that the level of the

This thesis extends the framework of Hall and Jones (2007) in medium to large scale quantitative OLG models, focusing on the interactions between endogenous life expectancy and human capital accumulation, optimal taxation, inequality, welfare and growth. In the chapter "The Macroeconomic Effects of Obesity", I study the presence and magnitude of the obesity externality in a quantitative, general equilibrium OLG model. I find that incorporating endogenous life expectancy, which depends on the Body Mass Index (BMI) has significant macroeconomic effects through the effective discount rate. Agents of unhealthy weight face a higher mortality risk, which increases the effective discount rate, affecting the agents' decision with respect to physical and human capital accumulation and therefore their future mortality[2]. In contrast to the standard models of exogenous heterogeneity with respect to the discount rate, government intervention can influence the effective discount of the agents per se, which enhances the effectiveness of government intervention such as policies to combat childhood obesity. The model also generates substantial wealth and income inequality which is endogenously generated due to the heterogeneity with respect to the effective discount rate affecting the welfare implications of government policy.

In the chapter "Health and Optimal Taxation" I revisit the Ramsey problem of optimal taxation in the OLG framework introducing endogenous life expectancy through investment in the level of health. I find that even with the standard assumptions that result in zero capital income taxation in OLG models, the optimal capital income tax is non-zero and that the level of the capital income tax is influenced by technological progress in the medical sector [3]. Our result stems from the wedge between the decentralized and second best allocation where in the latter the government has an incentive

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utility function is positive. The interpretation of the constant parameter is the value of life in terms of utility.

[2] Agents of unhealthy weight discount more heavily the effects of current food consumption on future BMI and subsequently their future quality of life and mortality risk.

[3] As shown by Garriga (2003) and Peterman (2013) respectively, when the government can descriminate between cohorts or the Frisch elasticity of labour supply is constant the capital income tax rate is zero with the standard class of utility functions that are separable in their arguments.

to distort the optimal consumption path of the household. In a nutshell, since life expectancy is endogenous and the government can influence the demographic structure of the population, the weight between present and future consumption is not identical between the household and the government, which results in a positive or negative capital income tax in order to influence future consumption.

In the chapter “The Effects of Pension Reform on Health Care Spending”, I study the fiscal implications of increasing the retirement age as a response to the ageing population and increasing life expectancy. I find that agents increase the demand for health care spending in order to be fit to work for longer, further increasing life expectancy which partly offsets the positive effects of the retirement age reform on dependency ratios. Furthermore, I find that as long as health care spending is at least partly subsidized the fiscal impact of reduced pension payments is partly offset by an increase on the level of health care subsidies.

The main contribution of this thesis is to demonstrate that the macroeconomic effects of endogenous longevity are important with respect to fiscal policy, capital accumulation and welfare. Hence, even though the properties of the OLG models with respect to dynamic inefficiency can be explained solely by the mechanism of “births” as discussed in Weil (2008), how the agents vanish from the economy has important implications for government policy and it’s of prime interest.

Chapter 2

The Macroeconomic Effects of Obesity

2.1 Introduction

The rising prevalence of obesity during the last decades both in developed and developing countries has raised concern among policy makers and health practitioners. Obesity has direct linkages with several diseases such as Diabetes Mellitus, Cardiovascular Disease and several types of cancer (see inter alia Must et al. (1999), Ng et al. (2014)) and has significant effects on life expectancy (Fontaine et al., 2003). Furthermore, obesity has direct and indirect economic costs which burden the health care systems (see inter alia Allender and Rayner (2007), Wang et al. (2011), Scarborough et al. (2011)) and the individuals themselves through lower wages (Dackehag, Gerdtham and Nordin, 2014) and lost working hours (Trogdon et al., 2008). In an effort to tackle the obesity epidemic, governments have considered or implemented various measures such as labeling of food products (Trogdon et al., 2008) and taxes on 'unhealthy' foods or 'healthy food subsidies' (see Yaniv, Rosin and Tobol (2009)). However, weight is a matter of personal choice (Philipson and Posner, 2003) and unless overweight and obese individuals do not internalize their choices, government intervention can reduce welfare.

The contribution of this paper is twofold. First, in contrast to the literature that focuses on the direct and indirect costs of obesity (see inter alia Wang et al. (2011) and Cawley and Meyerhoefer (2012)), we estimate the net fiscal burden of obesity taking into account not only the excess health care spending caused by overweight and obese individuals, but also the social security benefits and the life-time contributions through taxation. This is crucial, since on the one hand obese individuals face higher medical costs and are expected to pay less contributions throughout their life-time[1], but on the other hand their life expectancy is lower, resulting in fewer periods of health care spending and social security benefits. In countries such the UK, where the health care system is dominated by a single-payer, publicly funded National Health Service (NHS) focusing solely on the health care cost of obesity does not account for the overall fiscal impact of excess weight[2].

Second, this paper assesses the impact of government intervention in a general equilibrium, overlapping generations model where (i) food consumption and weight, (ii) labour productivity and (iii) life expectancy are endogenous. In contrast to other health hazards like smoking, obesity is caused by relative overconsumption[3] of a basic human need, food. Hence, untargeted fiscal policies such as a soda tax, affect all individuals and the welfare and economic benefits of reducing the prevalence of obesity become unclear. Furthermore, tackling the obesity epidemic has direct and indirect

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[1] With proportional income, consumption and capital income taxes, individuals with lower labour productivity are expected to pay less taxes ceteris paribus

[2] In countries such as the US where private insurance is more common, the effect of obesity on health care costs is assessed through health insurance premiums (Bhattacharya and Sood, 2006).

[3] Excess weight is caused by calorific imbalance, where individuals consume more calories than they expend. Even though the consumption of calories is falling over time, energy expenditure is falling even faster (Griffith, Lluberas and Lührmann, 2016) resulting in a relative overconsumption of calories

macroeconomic consequences through labour productivity and life expectancy, which subsequently affects the spending and saving decisions of the household through the effective discount rate.

Our results show that only the top 30% of the BMI distribution have negative, albeit small, net contributions. In fact, individuals at the top 5% of the BMI distribution have a life-time net deficit between 4.42% and 5.81% of annualized per capita GDP ($1933 to $2540 in 2015), depending on the burden of obesity on health care spending. In our model, we observe a relatively low impact of obesity on government spending even though obese individuals pay less taxes throughout their lifetimes and have higher medical costs that increase non-linearly with BMI. This is the outcome of higher mortality rate among obese individuals which results in fewer periods of pensions payments and medical services.

An additional feature of the benchmark model is that it generates substantial income and wealth inequality which is consistent with the observed socio-economic gradient of obesity[4]. There are two sources for the observed inequality in our model, (i) lower productivity and (ii) lower life expectancy which affects the effective discount of the agents. In our counterfactual simulations where we shut-down the productivity channel, more than 65% of the increase in inequality can be attributed to the higher effective discount rate. The endogenous effective discount rate caused by higher mortality has multiple consequences for the individual; (i) lower asset accumulation, (ii) discounting the adverse effects of obesity on future labour productivity, (iii) future medical spending and (iv) future mortality risk.

Having setup and estimated the model we are able tow carry out two important policy

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[4] Introducing obesity, endogenous mortality and labour productivity in an otherwise standard overlapping generations model, we observe an increase of the wealth Gini coefficient by 1.36 percentage points and the net income Gini coefficient by 0.55 percentage points compared to the benchmark case. The impact of obesity on inequality is quantitatively large compared to the largest increase in the Gini coefficient in British history by 9 percentage points between 1970-'90 (Cribb et al., 2017).

expericements and quantify the magnitude of key macroeconomic effects; the elimination of (i) childhood obesity and (ii) the VAT exemption of specific categories of food consumption, both policy relevant interventions. Childhood obesity has drawn a lot of attention in the literature (Cawley, 2010) both for the direct economic and welfare costs of childhood obesity per se and the higher risk of obese children to become obese adults (Serdula et al., 1993), with subsequent effect on future labour productivity, life expectancy and quality of life. Taxing specific food categories such as food high in fat and sugar are advocated from health practitioners (Brownell et al., 2009) and have been implemented or under consideration in various countries such as the UK[5] and Denmark[6]. We find that the welfare and economic impact of eliminating childhood obesity are substantial, with an increase in welfare of 10.5% of equivalent consumption, an increase in GDP by 2.15% and a reduction of the NHS budget by $1.48 billion, while the obesity externality is effectively eliminated. With respect to the VAT reform, the results are more modest with respect to the magnitude but remain significant. The aggregate welfare gains are 0.26% of equivalent consumption, however the policy is not Pareto optimal. The bottom 20% of the BMI distribution losses up to 0.41% of equivalent consumption, while the rest of the BMI distribution experience welfare gains up to 0.6% of equivalent consumption. Our study is related to two strands in the literature, the general equilibrium literature on obesity (see inter alia Lakdawalla, Philipson and Bhattacharya (2005) and Dioikitopoulos, Katsaiti and Shaw (2012)) and the empirical literature that studies the economic cost of obesity (see inter alia Bhattacharya and Bundorf (2009), Trogdon et al. (2008) and Scarborough et al. (2011)). However, to the best of our knowledge, the literature hasn't focused on the fiscal implications of obesity in a general equilibrium model with endogenous labour supply. The general equilibrium literature attempts to shed light on the mechanisms that increased the prevalence of obesity over the last decades in both developed and developing countries. We follow the methodology of this literature in order to answer

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[5] A tax on soft drinks will take effect from April 2018 in the UK

[6] Denmark introduced a "fat" tax on food with more than 2.3% of saturated factor but it was later abolished.

a different question in a more quantitative setting. We extend the model of Lakdawalla, Philipson and Bhattacharya (2005) in an overlapping generations model by incorporating endogenous life expectancy and productivity, both depending on weight, social security provisions such as public health care spending and a pay-as-you-go pension scheme and assess the macroeconomic impact of obesity and government interventions to tackle the obesity epidemic.

The rest of the paper is organized as follows. In the next section we set up the economic environment under which we are going to study the presence and magnitude of externalities caused by obesity. In section 1.3, we describe the functional forms and the estimation of the parameters relevant for our model. In sections 1.4 and 1.5, we present the quantitative results and analyze the economic implications of policy interventions respectively. We conclude with section five.

2.2 The Economic Environment

Consider an economy inhabited by overlapping generations of agents who survive for a maximum of J periods. Agents derive utility from general consumption, the consumption of food, leisure and their body mass index (BMI)[7]. The latter is determined by net calorific balance- the consumption of food and energy expenditure during labour and leisure and affects the level of utility non-monotonically as in Philipson and Posner (2003) and Lakdawalla, Philipson and Bhattacharya (2005). In addition, BMI affects the life expectancy, labour productivity and health care costs of the agent.

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[7] The level of BMI is determined by weight (in kg) over height squared (in meters). The introduction of BMI in the utility function serves two purposes; first, it is a realistic representation of individual preferences, since individuals care about their level of weight, an assumption that we test empirically in Section 1.3. Second, in order to assess the welfare implications of government policy, we need to take into account not only the direct and indirect economic implications of the obesity epidemic but also the quality-of-life implications of reducing the prevalence of obesity.

There is a representative firm which produces a single composite good utilizing capital and labour. Finally, the government runs a balanced budget every period, taxing capital income, labour income, general consumption, food consumption and provides health care subsidies for all cohorts and a Pay-As-You-Go social security scheme for cohorts $j > J_R$.

2.2.1 Demographics

Time is discrete and the model is populated by J overlapping generations. At the beginning of each period t, a measure of agents is born, whose mass grows at a constant rate n. Agents are ex-ante heterogeneous over two dimensions; preferences with respect to food[8] and initial BMI and the strenuousness of their occupation. The distribution of each type of agent i is predetermined and calibrated to match the UK data. The agents do not survive with certainty to the next period, but face a probability of survival $p^i_{j,t}\left(W^i_{j,t}\right) < 1$, which depends of their age j and their BMI $W^i_{j,t}$. At age $j = J$, agents have a probability of survival $p_{J,t} = 0$. There is no bequest motive, however deceased agents leave unintended bequests that are seized by the government and transferred back to the agents via a lump-sum payment as in Conesa, Kitao

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[8] For sensitivity analysis we set the preference uniform across all agents, differentiating solely with respect to their initial level of BMI. We find that our qualitative results do not change, however without heterogeneity with respect to preferences the model struggles to produce a BMI distribution that is close to the UK data, an important quantitative aspect of our model in order to estimate accurately the life-time net benefits of each percentile of the BMI distribution.

and Krueger (2009)[9]. Retirement is compulsory at age J_R and agents smooth their consumption through savings accumulated during their working life and pension benefits b_t that are a fraction χ of the average labour income in the economy, irrespectively of the idiosyncratic labour income earnings history of the agent.

2.2.2 Agents

Agents are endowed with one unit of time which they allocate between labour and leisure and enter the economy without assets. They derive utility from general consumption, the consumption of food, leisure and their BMI. Their life-time utility of an agent of type i is denoted as:

$$U^i = \sum_{j=1}^{J} \beta^{j-1} P^i_{j,t}\left(W^i_{j,t}\right) u^i_{j,t}\left(c^i_{j,t}, f^i_{j,t}, h^i_{j,t}, \Omega^i_{j,t}\left(W^i_{j,t}\right)\right) \tag{2.1}$$

with:

$$P^i_{j,t}\left(W^i_{j,t}\right) = \prod_{k=1}^{j-1}\left[p^i_{j,t-k}\left(W^i_{k,t}\right)\right] p^i_{j,t}\left(W^i_{j,t}\right) \tag{2.2}$$

where j denotes age, $c^i_{j,t}$, $h^i_{j,t}$ and $f^i_{j,t}$ are general consumption, labour supply and food consumption in period t for an agent of type i of age j respectively, β is the discount factor, while $p^i_{j,t}\left(W^i_{j,t}\right)$ denotes the probability of surviving to age cohort j, conditional on surviving until $j-1$ and $P^i_{j,t}\left(W^i_{j,t}\right)$ the unconditional probability of being alive at age j. $\Omega^i_{j,t}\left(W^i_{j,t}\right)$ denotes the utility derived from weight which is assumed to be inverted U-shaped since the agents have an ideal level of BMI as in Philipson and

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[9] There are two other possible specifications regarding bequests; the first are bequests that are simply seized by the government and are not distributed back to the agents, acting essentially as a 100% inheritance tax. The second are "warm glow" savings that act as intended bequests and are part of the utility function. Neither of these specifications affects the qualitative results of this paper. In the first, the labour income tax, which acts as a residual in our model in order to balance the government budget, would be lower since the government has an additional source of income. In the second specification, all the agents have a uniform, higher incentive to accumulate savings, which would result in higher aggregate savings, without affecting the rest of our analysis.

Posner (2003) and Lakdawalla, Philipson and Bhattacharya (2005). In essence, we assume that the quality of life of the agents deteriorates as they become underweight or overweight.

The households face the following budget constraint:

$$\begin{aligned} &(1-\tau^{w})\left(h^{i}_{j,t} w_t \varepsilon\left(j, W^{i}_{j,t}\right)\right) + \left(1 + r\left(1-\tau^{a}\right)\right) a^{i}_{j-1,t-1} + b_t + beq_t = \\ &= \left(1+\tau^{c}\right) c^{i}_{j,t} + \left(1+\tau^{f}\right) f^{i}_{j,t} + \left(1+\tau^{m}\right) m^{i}_{j,t}\left(W^{i}_{j,t}\right) + a^{i}_{j,t} \end{aligned} \tag{2.3}$$

where τ^{w}, τ^{m}, τ^{c}, τ^{f} and τ^{a} denote tax rates on labour income and health care spending, composite good consumption, food consumption and capital income respectively and beq_t denotes the accidental bequests of previously deceased agents that are transferred back to alive agents via the government. Agents receive retirement benefits b_t after the the compulsory retirement age J_R, which is a fraction χ of the average labour income during the working periods. The wage rate and interest rates are denoted as w_t and r_t respective and $a_{j,t}$ denotes savings. Agents have an age and weight specific level of productivity $\varepsilon_t\left(j, W\right)$, which consists of an exogenous age-specific productivity profile as in Conesa, Kitao and Krueger (2009) and an endogenous component which depends on weight. Furthermore, agents face medical spending $m^{i}_{j,t}$ that needs to be paid in order to survive to the next period as in Attanasio, Kitao and Violante (2010) and it depends non-linearly on BMI[10].

2.2.3 Firms

There are three sectors in the economy, the food sector, the medical sector and the sector that produces the rest of the goods and services. However, we assume that all sectors share the same production function and since capital and labour can move freely

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[10] This assumption is strongly supported by empirical evidence (de Gonzalez et al., 2010) and it takes into account that (i) both underweight and overweight individuals face higher medical costs due to unhealthy weight and (ii) increasing deviations from healthy weight have non-linear effects on health.

between sectors, the economy collapses into a one-sector economy. Hence, there is one representative firm, hiring labour and capital in order to produce a single composite good whose technology is described by a Cobb-Douglas production function:

$$Y_t = AK_t^a \tilde{L}_t^{1-a} \quad \forall t \tag{2.4}$$

where A_t denotes the total factor productivity[11] and K_t, $\hat{L}_t$ denote aggregate capital and effective labour at time t as in:

$$K_t = \frac{\sum\limits_{i=1}^{I} \sum\limits_{j=1}^{J-1} \psi_t\left(i,j\right) a^i_{j,t-1}}{(1+n)} \quad \forall t \tag{2.5}$$

and

$$\hat{L}_t = \sum_{i=1}^{I} \sum_{j=1}^{j_R-1} \psi_t\left(i,j\right) h^i_{j,t} \varepsilon^i_{j,t}\left(j,W\right) \quad \forall t \tag{2.6}$$

Let Ψ_t denote the mass of the total population, which is normalized to one, n the rate of population growth and $\psi_t\left(i,j\right)$ the mass of agents of type i and age j with a law of motion:

$$\psi_t\left(i,j\right) = \frac{p_t\left(i,j\right) \psi_{t-1}\left(i-1,j-1\right)}{1+n} \tag{2.7}$$

2.2.4 The Government

The government runs a balanced budget every period, collecting taxes from composite consumption, food consumption, labour income and capital income in order to finance an exogenous sequence of government spending G_t, pension payments and subsidize

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[11] Due to the agent's preference specification, the economy is not on the balanced growth path and A is time invariant (King, Plosser and Rebelo, 1988).

health care spending as in[12] :

$$\tau^c C_t + \tau^f F_t + \tau^m M_t + \tau^a K_{t+1} + \tau^w w \tilde{L} = G_t + B_t \quad \forall t \tag{2.8}$$

with C_t, M_t, F_t denote the aggregate levels of consumption, medical spending and food consumption respectively, G_t denotes government consumption and B_t denoting aggregate pension benefits.

The aggregate resource constraint of the economy is given by:

$$C_t + K_t + M_t + F_t + G_t - (1-\delta) K_{t-1} = A K_{t-1}^{\alpha} \tilde{L}_t^{1-\alpha} \tag{2.9}$$

2.2.5 Competitive Equilibrium

Here I present the formal definition of the competitive equilibrium. The agents' state variables are assets a, BMI W, their type i and age j.

Definition 1. (Competitive Equilibrium): *Given fiscal policy* π: $\{\tau_t^a\}_{t=0}^{\infty}$, $\{\tau_t^w\}_{t=0}^{\infty}$, $\{\tau_t^c\}_{t=0}^{\infty}$, $\left\{\tau_t^f\right\}_{t=0}^{\infty}$, $\{\tau_t^m\}_{t=0}^{\infty}$, $\{\chi_t\}_{t=0}^{\infty}$, $\{G_t\}_{t=0}^{\infty}$ *a competitive equilibrium for this economy is the sequence of individual allocations* $\left\{\left\{\left\{c^i_{j,t}, f^i_{j,t} h^i_{j,t}, m^i_{j,t}, a^i_{j,t}\right\}_{j=1}^{J}\right\}_{i=1}^{I}\right\}_{t=0}^{\infty}$, *production factors* $\{K_t, L_t\}_{t=0}^{\infty}$ *and relative prices* $\{r_t, w_t\}_{t=0}^{\infty}$, *such that:*

1. *Households maximize life-time utility (2.1) subject to their budget constraint (2.3) for all t*

2. $$c^i_{j,t} \geq 0 \quad f^i_{j,t} \geq 0 \quad a^i_{j,t} \geq 0 \qquad \forall t,$$

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[12] The agents face an endogenous level of health care spending that needs to be paid in order to survive to the next period and the government subsidizes a constant fraction τ^m. In other words τ^m is negative.

3.

$$0 \leq h^i_{j,t} \leq 1, \quad b_t = 0, \quad for \quad j < J_R \quad \forall t,$$

4.

$$h^i_{j,t} = 0, \quad b_t = \bar{b}, \quad for \quad j \geq J_R \quad \forall t,$$

5. *Prices w_t and r_t satisfy:*

$$w_t = (1-a)\frac{Y_t}{\hat{L}_t} \quad \forall t, \tag{2.10}$$

$$r_t = a\frac{Y_t}{K_{t-1}} - \delta \quad \forall t, \tag{2.11}$$

6. *Aggregate pension benefits and bequests are given as:*

$$B_t = \sum_{i=1}^{I}\sum_{j=1}^{J-1} \psi_t(i,j)\, b_t \quad \forall t \tag{2.12}$$

$$beq_t = \sum_{i=1}^{I}\sum_{j=1}^{J} \psi_t(i,j)\left(1 - p^i_{j,t}\right) a^i_{j,t}\left(1 + r_t\left(1 - \tau^{\alpha}\right)\right) \quad \forall t \tag{2.13}$$

7. *Aggregate general consumption, food consumption and medical spending are given as:*

$$C_t = \sum_{i=1}^{I}\sum_{j=1}^{J-1} \psi_t(i,j)\, c^i_{j,t} \quad \forall t \tag{2.14}$$

$$F_t = \sum_{i=1}^{I}\sum_{j=1}^{J-1} \psi_t(i,j)\, f^i_{j,t} \quad \forall t \tag{2.15}$$

$$M_t = \sum_{i=1}^{I}\sum_{j=1}^{J-1} \psi_t(i,j)\, m^i_{j,t} \quad \forall t \tag{2.16}$$

8. *Markets clear:*

$$K_{t-1}(1+n) = \sum_{i=1}^{I}\sum_{j=1}^{J-1} \psi_t(i,j)\, a^i_{j,t} \quad \forall t, \tag{2.17}$$

$$\hat{L}_t = \sum_{i=1}^{I}\sum_{j=1}^{j_R-1} \psi_t(i,j)\, h^i_{j,t}\varepsilon^i_{j,t}(j,W) \quad \forall t \tag{2.18}$$

9. *The government budget constraint (2.8) is satisfied for all t*
10. *The resource constraint (2.9) holds for all t*

2.3 Calibration and Functional Forms

2.3.1 Demographics

We use a 15-period model in order to capture the life-cycle aspect of obesity in a macroeconomic setting. Agents are born at the age of 20 ($j = 1$), they retire at the age of 65 ($J_R = 9$) and survive at most at the age of 95 ($J = 15$). Thus each period in our model last 5 years. Population grows at a rate of $n = (1 + 0.006)^5 - 1 = 0.03$. The conditional probability of survival is denoted as:

$$p^i_{j,t}\left(W^i_{j,t}\right) = 1 - \rho\left(W^i_{j,t}\right)\Phi\left(j, t\right) \tag{2.19}$$

where $\rho^i_{j,t}\left(W^i_{j,t}\right) \in [1, \infty)$ denotes the hazard risk associated with weight and $\Phi\left(j, t\right) \in (0, 1)$ is the age-specific, conditional probability of death. de Gonzalez et al. (2010) using data encompassing 1.46 million white adults find that the effect of BMI on mortality risk is non-linear and increasing both for underweight and overweight individuals, after controlling for age, physical activity, alcohol consumption, education, and marital status. Since we need a functional form for hazard risk, in order to endogeneize the hazard risk associated with BMI, we fit the curve using OLS and estimate the parameters of the non-linear relation between BMI and risk hazard as in[13]:

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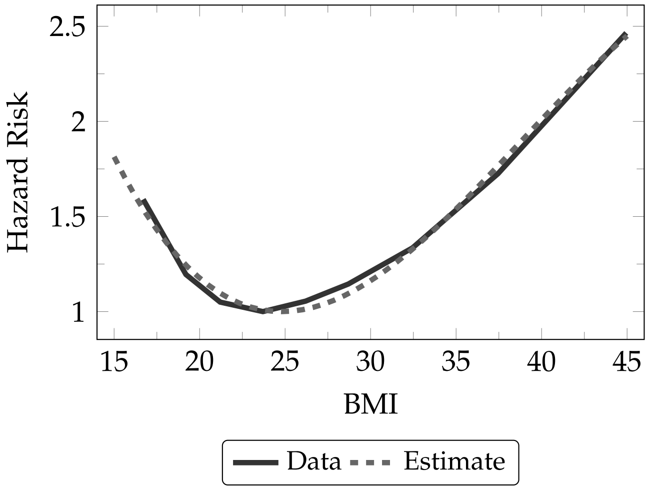
[13] We postulate a cubic relation between BMI and hazard risk because the quadratic equation does not provide a good enough fit for such a fundamental variable in our model. Since the level of BMI does not deviate to values that would result in decreasing risk for extremely low and high values of BMI, we make use of this formulation.

$$\rho^i_{j,t}\left(W^i_{j,t}\right) = \rho_0 + \rho_1 W^i_{j,t} + \rho_2\left(W^i_{j,t}\right)^2 + \rho_3\left(W^i_{j,t}\right)^3 \tag{2.20}$$

In a nutshell, we assume that agents face a baseline probability of death which is increasing with age and deviations from the medically optimal BMI amplify the probability of death. Our results suggest that $\rho_0 = 7.72$, $\rho_1 = -0.64$, $\rho_2 = 0.02$ and $\rho_4 = 0.0001$[14].

Figure 2.1: Relation between BMI and mortality hazard risk



Notes: Data are obtained from de Gonzalez et al. (2010). We estimate a non-linear equation using OLS in order to fit the hazard curve.

The exogenous probability of death is taken from the Human Mortality Database (2007) with the latest available data being for the year 2014. Since the data refer to the population as a whole with an average BMI above the healthy levels, we adjust the exogenous probability of death in order to derive the age-specific mortality risk of a healthy BMI agent. We estimate the average BMI per age group using data from the Health Survey for England in year 2014 and using the hazard risk as estimated above, I adjust the age specific mortality risk. This ensures that the average mortality risk

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[14] In this estimation we are not attempting to address the effect of BMI on hazard risk, since we use the estimation of de Gonzalez et al. (2010). Instead, we make use of the non-linear relation obtained in their results in order to estimate the parameters of our specification.

derived from our simulations does not double count the hazard risk associated with excess weight, which would inflate the probability of death.

2.3.2 Preferences

Agents derive instanteneous utility from general consumption, food consumption, leisure and BMI:

$$u^i_{j,t} = \frac{c^{1-\gamma}_{j,t}}{1-\gamma} + \varphi^i \frac{f^{1-\sigma}_{j,t}}{1-\sigma} + \nu \frac{\left(1-h_{j,t}\right)^{1-\eta}}{1-\eta} + \Omega\left(W_{j,t}\right) \tag{2.21}$$

We set the coefficients of relative risk aversion as $\gamma = 2$, $\eta = 3$ (Conesa, Kitao and Krueger, 2009), $\sigma = 2$ and we calibrate the relative weights of food and leisure in order to match the average share of food consumption as a percentage of GDP in the UK in 2014 (Living Costs and Food Survey, 2014) and a level of average labour supply equal to 0.3 respectively (approximately 8 hours per day). In our model agents are ex-ante heterogenous with respect to food preference, in order to reflect the genetic differences with respect to food satiation. This choice is strongly supported by medical research which suggest that genetic factors explain 40-70% of weight variation (see inter alia Waalen (2005), Elks et al. (2012); Haworth et al. (2008)). The utility derived from BMI is denoted as in Dioikitopoulos, Katsaiti and Shaw (2012) who follow the intuition Philipson and Posner (2003):

$$\Omega^i_{j,t}\left(W^i_{j,t}\right) = \omega_0 + \omega_1 W^i_{j,t} + \omega_2 \left(W^i_{j,t}\right)^2 \tag{2.22}$$

Agents are assumed to have an ideal level of BMI which is uniform across agents, with ω_0 and ω_1 being positive and ω_2 being negative. Hence, any deviations from the ideal level of BMI have a detrimental effect on utility influencing the optimal allocation of the household with respect to consumption, food consumption and leisure.

We verify the non-monotonic relation between BMI and utility with OLS using data from the Health Survey for England, using different specifications and controls[15]. For robustness, we choose two different proxies for felicity, the Warwick-Edinburgh Mental Wellbeing Scale (WEMWBS) and the 12-item General Health Questionnaire (GHQ-12) that assess the mental wellbeing of the respondents[16]. We control for age, marital status, income quantile, education, illness status, smoking status, a dummy for children in the household and a dummy for the type of dwelling. Under all specification, the BMI coefficients are statistically significant and suggest that BMI affects mental wellbeing non-monotonically.

2.3.3 The evolution of BMI

The specification for the evolution of BMI is fundamental in our model, since it affects the individual allocation and subsequently all the endogenous variables that depend on BMI, such as the probability of survival and labour productivity. We make use of a specification as in (Hall et al., 2011), which is an application of the first law of thermodynamics. Hence, the level of BMI depends on the previous period BMI and the net calorific balance, meaning that if agents expend as many calories as they consume their BMI does not change[17]:

$$W^i_{j,t} = W^i_{j-1,t-1} + \xi f^i_{j,t} - R_{j,t}\left(s^i_t h^i_{j,t} + \bar{s}_t\left(1 - h^i_{j,t}\right)\right) \tag{2.23}$$

with $W^i_{j-1,t-1}$ being the weight of the previous period, ξ transforms food consumption

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[15] For details consult Appendix B, Table 2.B.1

[16] The WEMWBS scale ranges from 14-70 with higher values denoting better mental wellbeing. The GHQ-12 has a minimum value of 0 and a maximum value of 12, with lower values being better. Both questionnaires assign score values to each question and add them up to create an aggregate score

[17] Energy, which is the case of excess weight is stored fat, cannot be created from nothing and cannot be destroyed. Hence, energy consumed must either be expended or stored

into calories, $R_{j,t}$ denotes the age-specific basal metabolic rate (BMR)[18], s_t^i denotes the degree of strenuousness of working, which is sector specific and $\bar{s}_t$ denotes the strenuousness of leisure time which is constant for all agents.

We estimate the age-specific BMR using the Mifflin-St. Jeor equation (Mifflin et al., 1990) which is a good approximation of the average metabolic rate of the population (Hall et al., 2012) and depends of gender, height, weight and age[19]. We calculate the BMR of every individual after the age of 20 in our dataset, using the Mifflin-St. Jeor equation and then we take the average per age group. This ensures that the average BMR per age reflects the characteristics of our dataset, and the UK distribution of weight, height and gender in the population.

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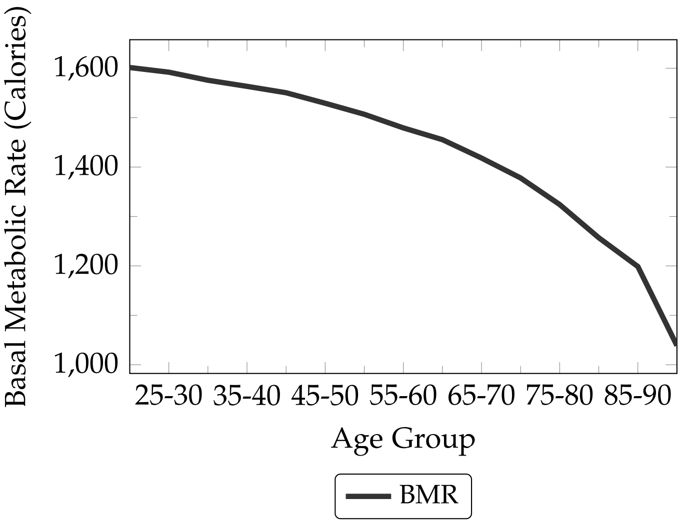
[18] BMR is the minimum daily expenditure of a person that spends 24 hours at rest.

[19] The Mifflin et al. (1990) equation is described as :$BMR = 10.0m + 6.25h - 5.0a + s$, where m is the weight in kg, h is the height in meters, a is age and s is a constant gender specific parameter, where $s = 5.0$ for men and $s = -151$ for women. The level of BMR depends on the energy expenditure of the human body in order to survive. This depends on the body mass and the body composition. Men and younger individuals have a greater percentage of muscle compared to women and older individuals, which is more energy intensive to maintain. In addition, taller and heavier individuals need more calories to sustain their bodies. These mechanisms are described in the Mifflin et al. (1990) equation.

Figure 2.2: Age-Specific Basal Metabolic Rate



Notes: I estimate the age-specific Basal Metabolic Rate using the Mifflin et al. (1990) from the pooled data of the Health Survey for England, 2011-2014. The equation takes into account the gender, reported height and weight and age of the respondent.

Our results suggest that the average BMR falls with age (Figure 2.2), even though the gender composition does not change until the later stages of life[20] and the prevalence of obesity increases with age, as described in the next section. This underlines the strong effects of age on BMR since the muscle composition falls with age, reducing the energy expenditure at rest. This has important implications in our model since as agents age, reducing the level of BMI become increasingly harder.

The parameters s_t^i and $\bar{s}_t$ denote the strenuousness of working and leisure respectively and are expressed in terms of Metabolically Equivalent Task (MET), which is the ratio of the energy expended during a given task over the BMR. Since not all occupations are equally strenuous, for example a desk job is far less strenuous than a construction occupation, we need to take into account the distribution of occupations and their respective strenuousness level, in order to accurately reproduce the BMI distribution

---

[20] Women have higher life expectancy than men.

of the UK economy. In order to estimate the distribution and the level of strenuousness of the working population in the UK we do the following; first, we calculate the percentage of the workforce working in each occupation using the Standard Occupational Classification (SOC2010) and then we assign MET values for each occupation using data from Tudor-Locke et al. (2011) (Table 2.1).

Finally, in order to simplify our analysis, we reduce the level of strenuousness in three categories; sedentary, moderate and strenuous, whose values and distribution are used in our parameterization[21]. We group the percentage of the working population that is working in occupations with strenuousness level of [1,2], (2,3] and above 3 as sedentary, moderate and strenuous respectively. For example employees of administrative occupations expend 1.83 times more calories while working compared to being at rest and are classified as sedentary, while employees of process plant and machine operatives occupations expend 3.19 times more calories than being at rest and are classified as strenuous.

TABLE 2.2: STRENUOUSNESS

Level of Strenuousness	% of Workforce
Sedentary	52.02
Moderate	28.72
Strenuous	19.26

Notes: The percentage of workforce employed in each level of strenuousness are derived from Table 2.1 in Appendix B. Sendetary occupations are considered the ones with a level of MET of 1-2, moderate with a level of 2-3 and strenuous with above 3.

The value of MET during leisure $\bar{s}_t$ is constant for all agents and is the average of the strenuousness of leisure estimated by Griffith, Lluberas and Lührmann (2016), taking

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[21] The results are close to the estimation of Griffith, Lluberas and Lührmann (2016), with a slightly higher percentage of sedentary occupations, which refers to the year 2009 using the a different occupational classification. We rely on our own estimates, since as is evident in the results of Griffith, Lluberas and Lührmann (2016), the distribution of the strenuousness of occupation changes over time, with occupations becoming increasingly more sedentary. Hence, we use the latest available data with the most recent Standard Occupational Classification.

TABLE 2.1: OCCUPATIONAL CLASSIFICATION AND METABOLIC EQUIVALENT TASK

Standard Occupational Classification (SOC2010)	% of Workforce	MET
Corporate managers and directors	5.69	1.73
Other managers and proprietors	3.23	1.73
Science, research, engineering and technology	4.5	1.64
Health professionals	4.08	2.22
Teaching and educational professionals	6.05	2.5
Business, media and public service professionals	4.64	2.13
Science, engineering and technology associate professionals	1.49	1.64
Health and social care associate professionals	1.38	2.83
Protective service occupations	0.99	2.56
Culture, media and sports occupations	1.75	2.13
Business and public service associate professionals	6.46	1.67
Administrative occupations	9.98	1.83
Secretarial and related occupations	3.58	1.83
Skilled agricultural and related trades	1.15	3.67
Skilled metal, electrical and electronic trades	3.74	3.67
Skilled construction and building trades	2.98	3.67
Textiles, printing and other skilled trades	2.34	3.67
Caring personal service occupations	9.82	2.53
Sales occupations	6.07	2.00
Customer service occupations	1.27	2.00
Process, plant and machine operatives	7.37	3.19
Elementary trades and related occupations	1.69	3.67
Elementary administration and service occupations	9.75	2.00

Notes: The percentage of workforce employed in each Standard Occupational Classification are calculated from the pooled data of the Health Survey for England, 2011-2014. The values for the Metabolic Equivalent Task are assigned manually to the closest US classification as derived by Tudor-Locke et al. (2011)

into account sleep, home work and other activities.

2.3.4 Labour Productivity

The productivity of agents is determined by an exogenous age-specific profile and an endogenous component which depends on BMI.

$$\varepsilon^{i}_{j,t}\left(j,W\right)=\pi_{t}\left(j\right)e^{\zeta W^{i}_{j,t}} \tag{2.24}$$

The exogenous component $\pi_t\left(j\right)$ is calibrated to match the hump-shaped labour supply and labour income on the households (Huggett, 1996), while we calibrate the relation between BMI and productivity $e^{\zeta W^{i}_{j,t}}$. The estimation of the relation between labour productivity and obesity poses a series of challenges because of reverse causality and cofounding factors and the results in the literature are mixed. Dackehag, Gerdtham and Nordin (2014) use Swedish data in order to estimate the impact of obesity on labour income. Using OLS the results suggest that obese men lose approximately 6% of labour income compared to normal weight individuals, while the Fixed Effects regression increases the estimate to 9%. Both results are statistically insignificant for women. Nustad and Black (2011) study the loss in productivity directly, using the Work Limitations Questionnaire in US manufacturing workers and estimate that the loss of productivity is 1.18% compared to normal weight individuals. However, another source of lost productivity beyond presenteeism, is absenteeism[22]. Harvey et al. (2010) using data from the London Underground find that normal weight individuals lose on average 6 days per calendar year, while obese individuals lose 9.5-11 days per calendar year, hence 1.6-2.2% more working days[23][24].

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[22] Presenteeism is defined as the loss in productivity while on the job and absenteeism is defined as lost working days due to illness.

[23] According to the ONS statistics the calendar year has 226 working days for the average employee.

[24] It is well documented that public sector employees take more days of sick leave compared

We are aware of the uncertainty with respect to the effect of BMI on labour productivity and we take a conservative approach. In our benchmark model, we calibrate ζ such that a healthy BMI individual is 5% more productive than an obese individual, which is in the middle of the estimates, while in our counterfactual simulation we assume that BMI does not affect productivity.

2.3.5 Government Policies and Health Care Spending

The labour income tax rate is determined endogenously in order to balance the government budget, while consumption, food consumption, capital income and health care spending subsidies are calibrated or estimated. Food consumption is either taxed with a VAT of 0% or 20% and thus we need to estimate the effective tax rate on food consumption. Typically food prepared at home has a 0%[25] and eating out, soft drinks, confectionary and alcohol are taxed at a rate of 20%. Griffith, Lluberas and Lührmann (2016) estimate the expenditure allocation between different food categories for the UK for the period 2013-2017 and we apply these shares of expenditure to each VAT category and estimate an effective VAT of 9.7%. For general consumption, we apply the standard VAT of 20% since most of the excluded categories refer to food consumption. Capital income is taxed at an effective rate of 46% in the UK (Trabandt and Uhlig, 2011) and the government share of aggregate medical spending is 79%[26]. Finally, I set the pension replacement rate χ to 0.335, which is the average replacement ratio in the UK (OECD, 2017)

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to their private sector counterparts ONS (2017) and these estimates are follow closely the rate of absence in the public sector.

[25] This includes fruits and vegetables, meat and poultry but also chilled/frozen ready meals and convenience foods

[26] This is the average share of overall health care spending that is financed by the central government (OECD,2017). Since the UK health care system is dominated by the single-payer, government financed centralized National Health System we can abstract from the effects of private health insurance. I will consider the share of health care spending that is not covered by the government as out-of-pocket payments, which includes co-payments and over-the-counter medicine.

Health care spending and its relation with BMI is a fundamental feature of our model and since it can skew our results, we attempt to estimate it using data from the UK economy. Andreyeva, Sturm and Ringel (2004) show that there is a non linear relation between BMI and health care spending, meaning that both underweight and overweight individuals face higher medical spending and the higher the deviation from healthy weight, the higher the medical cost. In order to reflect this relation in our model, we postulate the following function for the health care spending of an agent of age j and type i:

$$m^{i}_{j,t} = \mu_0\left(j\right) + \mu_1\left(W^{i}_{j,t} - \bar{W}\right)^2 \tag{2.25}$$

where $\mu_0\left(j\right)$ is the exogenous, age-specific health care spending of a healthy weight individual and $\mu_1\left(W^{i}_{j,t} - \bar{W}\right)^2$ is the endogenous health care component that depends on the deviation of the healthy BMI. In essence, all agents of the same age at a healthy BMI face the same medical spending, and any deviations from that BMI result in a mark-up which needs to be paid in order to survive to the next period.

The parameters that we need to estimate are $\mu_0\left(j\right)$ and μ_1 and we proceed as follows; first, we estimate what percentage of the overall health care spending in the UK is directly caused by obesity, applying the methodology of Scarborough et al. (2011) on the 2016 NHS budget. Using the burden of specific diseases associated with obesity on the NHS budget and the Population Attributable Fractions (PAF), we estimate what percentage of these cost are caused by excess weight. For example diabetes mellitus, a common disease associated with excess weight, cost each year 1.3% of the NHS budget, of which 79% is attributed to overweight or obese patients (Table 2.3).

These estimates provide a lower bound since they only include direct cost of diseases that are directly associated with excess BMI. We also estimate the upper bound with respect to the health care costs of excess weight, taking into account the health care cost of poor diet and inactivity. Since not all overweight agents consume a poor diet and have low levels of physical activity and vice versa, the true health care cost of excess BMI lies between the two bounds. We find that accounting only for the direct cost of obesity, the NHS spends 6.3% of its budget to treat obesity-related diseases, while taking into account poor diet and physical inactivity the estimate for the cost of obesity rises to 14.56% of the NHS budget[27]. We make the simplifying assumption that these shares also apply to the aggregate health care spending; private and public combined[28]. Hence, the lower and upper bounds for the aggregate health care spending caused by unhealthy weight are 0.62% and 1.43% of GDP respectively, given the level of aggregate health care spending of 9.8% in 2016.

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[27] Poor diet and physical inactivity are directly responsible for 8.55% and 1.38% of the NHS budget respectively

[28] This means that the private share of health care spending in the UK that is spent on conditions related to obesity lies between 6.3%-14.56%. This assumption is not important for our results since the lion's share of health care spending in the UK is public, through the NHS.

TABLE 2.3: ECONOMIC COSTS OF OVERWEIGHT/OBESITY, POOR DIET, PHYSICAL INACTIVITY TO THE NHS

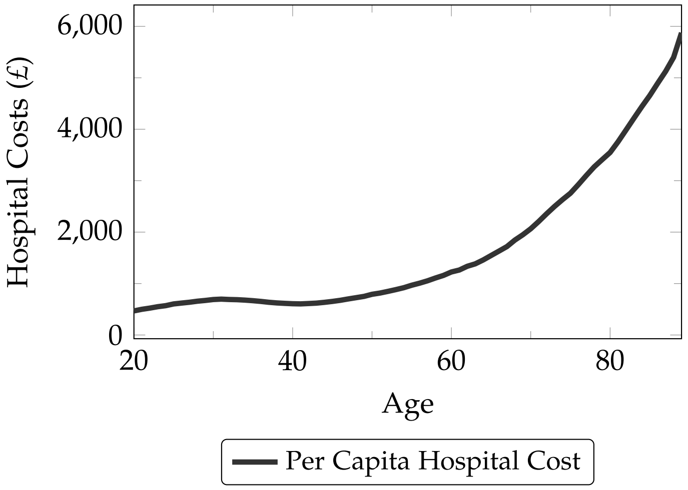
	% of Total NHS Costs	PAF	Total NHS Costs (in bn £)	% of Total Budget	Per Capita (in £)
Overweight and obesity					
Ischaemic heart disease	2.9	34	1.1832	0.986	18.2
Ischaemic stroke	1.2	34	0.4896	0.408	7.5
Breast cancer	0.6	12	0.0864	0.072	1.3
Colon/rectum cancer	0.5	16	0.09	0.075	1.4
Hypertensive disease	4.5	58	3.132	2.61	48.1
Corpus uteri cancer	0.2	49	0.1176	0.098	1.8
Osteoarthritis	5.0	21	1.26	1.05	19.4
Diabetes mellitus	1.3	79	1.2324	1.027	18.9
Total	11.6		7.5912	6.326	116.6
Poor diet					
CVD	9.2	22	3.6432	3.036	56
Diabetes mellitus	2.8	33	1.1088	0.924	17
Cancer	6.2	33	2.4552	2.046	37.7
Dental caries	3.4	33	1.3464	1.122	20.7
Total	21.6		8.5536	7.128	131.4
Physical inactivity					
Ischaemic heart disease	2.9	23	0.8004	0.667	12.3
Ischaemic stroke	1.2	12	0.1728	0.144	2.7
Breast cancer	0.6	11	0.0792	0.066	1.2
Colon/rectum cancer	0.5	16	0.096	0.08	1.5
Diabetes mellitus	1.3	15	0.234	0.195	3.6
Total	6.5		1.3824	1.152	21.2

Notes: Data for the percentage of total NHS budget dedicated to each condition and population attributable fractions (PAF) are taken from Scarborough et al. (2011). The NHS budget in 2016 was £120 billion

Thus, given the distribution of BMI in our simulations, μ_1 is calibrated such that $\sum_{j=1}^{J}\sum_{i=1}^{I}\mu_1\left(W_{j,t}^{i}-\bar{W}\right)$ is equal to 6.3% of aggregate health care spending in our benchmark model and 14.56% in our sensitivity analysis where we take into account the upper bound of obesity-related health care spending.

The exogenous component of medical spending $\mu_0\left(j\right)$ is calibrated such that $\sum_{j=1}^{J}\sum_{i=1}^{I}\mu_0\left(j\right)$ is equal to the residual of the aggregate health care spending, however we take into account that health care spending increases non-linearly with age. We use the data from Kelly, Stoye and Vera-Hernández (2015) who estimate the age-specific cost of hospital services in the UK. Assuming that the fraction of health care spending allocated to hospital services does not vary with age, we scale these estimates such that the aggregate exogenous component amounts to 9.18% and 8.37% of GDP for the lower and upper bounds with respect to excess weight costs respectively.

FIGURE 2.3: PER CAPITA HOSPITAL COSTS PER AGE



Notes: Data are obtained from Kelly, Stoye and Vera-Hernández (2015). The hospital costs are estimated as the average between men and women with equal weights.

According to the data (Figure 2.3), hospital costs are relatively stable until the age of 45, with a temporary increase during the child-bearing age, and subsequently increase exponentially as individuals age and their probability of survival decreases.

It should be noted that in our model we take into account the fact that the majority of medical spending takes place at the last two years of life (Zweifel, Felder and Meiers, 1999). Premature mortality caused by unhealthy weight does not underestimate the life-time medical spending, since the adverse effects of obesity are reflected in the endogenous component of individual health care spending. This means that an obese individual that has deceased by the age of 70 and doesn't face the significantly higher medical spending from the exogenous component of medical spending, faces high medical spending through the endogenous component of medical spending.

2.4 Steady State Results

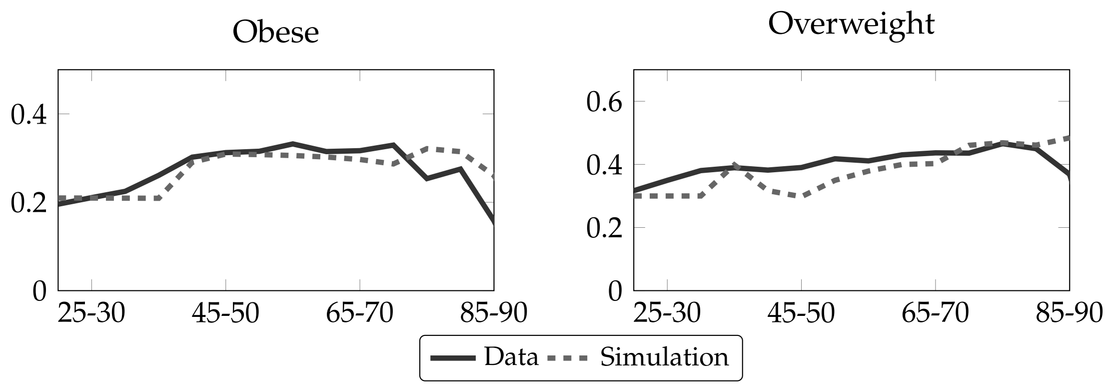
The model succeeds in producing key aggregate variables that are close to the actual UK economy. Aggregate health care spending amounts to 9.8% of GDP, with the private share being 2.0% of GDP and the rest being the public share. Public pensions, provided by a pay-as-you-go social security scheme, amount to 4.7% of GDP as in the UK data, which is a result of the model succeding to reproduce the demographic structure of the UK economy. Government consumption is calibrated to match the UK average of 19.4%, which results in a labour income tax of 20.3%, lower than the actual rate of 28%. This is the outcome of labour income tax acting as a residual that balances the government budget, which ignores transfers other than pensions and health care subsidies for the sake of simplicity.

TABLE 2.4: BENCHMARK MODEL STATISTICS

Name	Model	Data
Health Care Spending		
Aggr. Health Care Spending (% GDP) in 2015	9.8 %	9.8%
Private Share (% GDP) in 2015	2.0%	2.0%
Government		
Public Pensions (% GDP) in 2015	4.7%	4.7%
NHS Spending (% GDP) in 2015	7.7%	7.7%
Government Consumption (% GDP) in 2015	19.4%	19.4%
Labour Income Tax	20.3%	28%

Furthermore, our simulation results approximate the distribution of obese and overweight individuals in the economy taking into account food preferences, job strenuousness and mortality risk.

Figure 2.4: Percentage of Obese and Overweight by Age Group



Notes: Data are obtained from the Health Survey for England (2011-14). The simulation results are the weighted average BMI of each age group.

These results are important for the quantitative exercise of estimating the net benefits of each percentile of the BMI distribution. The model tracks the increase of the prevalence of obesity until the age of 65 and its subsequent fall. In our model, the fall in the prevalence of obesity can be explained through the higher mortality risk associated with unhealthy weight, namely obese individuals die younger and hence their share of the population falls. Regarding the distribution of overweight individuals, the model deviates from the UK data at later stages of life. One possible explanation is that the risk hazard estimated above, applies for the average age individual and being overweight at older ages increases the mortality risk substantially. Hence, our model would tend to underestimate the mortality risk of overweight individuals resulting in higher prevalence than observed in the data. Another possible explanation are cohort effects, namely older individuals today are less likely to be overweight because while they were younger, they were less likely to be overweight or obese compared to today's young generations. Finally, our estimates for the hazard risk associated with BMI rely on white, adult population and it is an established fact that different racial group have different classifications of unhealthy BMI (see for example Health Organization (2004)). Given the demographic composition of the UK economy, the divergence of the prevalence of overweight individuals is overestimated in our model at older ages.

On the disaggregated level, we face a fundamental issue that this parer attempts to address. Agents switch between BMI classifications (i.e. underweight, normal, overweight and obese) throughout their lifetime, with a general trend of increasing BMI (Meeuwsen, Horgan and Elia, 2010) that on an individual level can be reversed because of life-style choices and health shocks such as terminal diseases (Harrington, Gibson and Cottrell, 2009). In order to simplify the analysis, we ignore life-style changes and shocks that result in a reduction of BMI. With respect to the former, we consider this simplification reasonable since even though individuals can be successful in losing weight, out of the overweight or obese individuals that decide and accomplish to lose at least 10% of their weight, only 20% maintain the weight loss after one year, with the fraction further reduced for more extended periods (Wing and Phelan, 2005) and thus on the aggregate level the effect is insignificant. With respect to the latter, idiosyncratic shocks are not expected to have a significant impact on our results because health shocks that affect the level of BMI significantly are usually terminal[29] and affect agents that exit our model.

In this paper, we classify the agents based on their initial BMI which is calibrated to match the UK data at the age of 20 to 25[30] and track the whole life-cycle of the agents. This exercise is useful for two reasons; first, we can study the agents' life-cycle profiles with respect to asset accumulation, labour supply and their net contributions[31]. Classifying the agents solely based on their current BMI and estimating the net cost of obesity is misleading because agents are more likely to be obese as they age, ignoring their life-time contributions and overestimating the medical cost of obesity (see inter alia Trogdon et al. (2008), Wang et al. (2011) and Bhattacharya and Bundorf (2009)).

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[29] See for example cancer cachexia (Fearon, Voss and Hustead, 2006).

[30] Since agents switch between BMI classifications but not between BMI percentiles in our simulations, any age group as a point of reference would provide the same results.

[31] We define as net life-time contributions the sum of all tax payments made minus the total benefits received over an agent's lifetime.

Second, we can assess the significance of initial BMI and path dependence with respect to weight when analyzing the effectiveness of policy interventions. This is important for two reasons; first, the level of BMI is persistent in the sense that agents cannot achieve a healthy BMI overnight and they need to sustain a calorific deficit which is costly in terms of utility[32]. Secondly, policy interventions that affect the BMI distribution, directly affect the mortality rate and indirectly the effective discount rate of the agents. The latter has important implication on the individual and aggregate level since the effective discount rate affects the agents' decisions with respect to consumption, asset accumulation and BMI itself[33]. Hence, a general equilibrium overlapping generations model provides the framework to study the overall impact of policy interventions more accurately.

For the rest of the analysis, I will focus on three groups for clarity of exposition; the bottom 10%, the median and the top 10% of the life-time BMI distribution.

2.4.1 Asset Accumulation and Labour Supply

Our results show that the level of BMI has significant effects on asset accumulation and labour supply (Figure 2.5).

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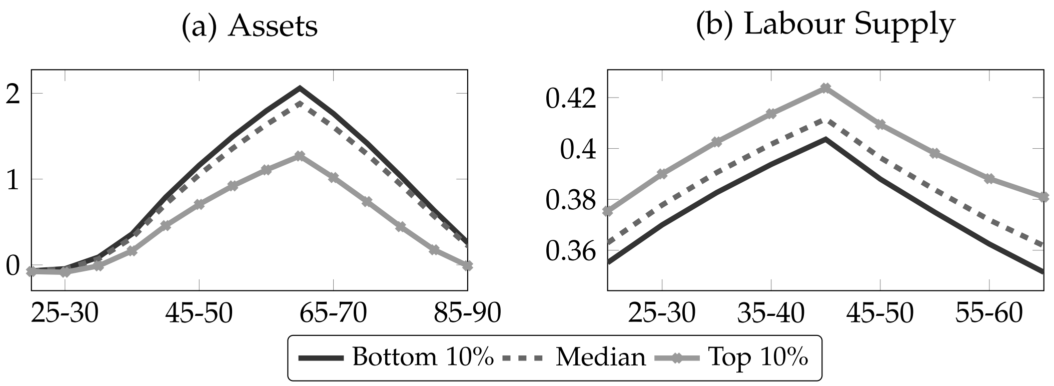
[32] In our model agents need to reduce the amount of food consumption in order to achieve a lower BMI, which is detrimental for the level of utility.

[33] An agent of unhealthy weight faces a lower probability of survival, which translates to a higher discount rate. Hence, agents of unhealthy weight tend to discount more heavily the effects of current food consumption on future BMI and its subsequent adverse effects on quality of life and life expectancy (see equation 2.1)

Figure 2.5: Simulation Results: Savings and Labour Supply



Notes: Simulation Results for the bottom 10%, the median and the top 10% of the BMI distribution.

Obese agents accumulate less assets for two reasons; (i) lower life expectancy (Figure 2.6) which tends to increase the effective discount rate and (ii) lower labour income (Figure 2.7). The latter affects asset accumulation not only because obese agents have less disposable income, but the drop in consumption after the retirement age is not as pronounced compared to healthy weight individuals, who in their attempt to smooth consumption accumulate more assets through their working lives in order to dissave during retirement[34].

The lower labour income throughout the working life-time of obese agents can be explained through lower productivity and lost working hours due to illness and not because of lower labour supply. In fact, obese individuals supply more labour throughout their working life (Figure 2.5). There are two possible explanations for this observation; first, obese individuals supply more labour because it's the only alternative source of weight loss besides reducing food consumption in our model[35]. This is a rational choice from the side of the agents, since even in sedentary occupations, time spent working is more strenuous than leisure, which would result in higher calorie

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[34] Recall that pensions are not conditional on individual life-time labour income but are fixed fraction of the average labour income of all workers in the economy.

[35] In order to simplify the model we have abstracted from exercise as a choice and hence the calories expended during leisure time are fixed.

expenditure. However, in our sensitivity analysis under which agents do not take into account the effect of labour on BMI when making the labour supply decisions, we find that our results are virtually unchanged and the higher labour supply as weight loss strategy is not a sufficient explanation[36].

Second, obese individuals supply more labour because they are poorer. Since obese agents hold less assets and earn a lower effective hourly wage, both their capital income and labour income are lower, which induces agents to increase their labour supply and hence increase their levels of consumption. This is not a peculiarity of our model, but it's a fundamental feature of general equilibrium models with endogenous labour supply. Agents face an intra-temporal trade-off between consumption and leisure, which results in higher labour supply for poorer household because of the income effect[37].

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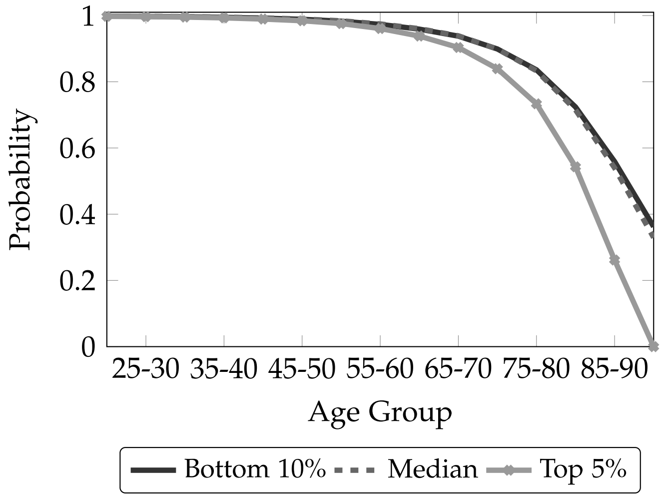
[36] Increasing labour supply in order to lose weight is ineffective for two reasons in our model. First, agents would have to gain direct and indirect utility (from a lower BMI and higher productivity and life expectancy respectively) which is high enough to compensate for the disutility from the increase in labour supply. Secondly, even though working is more strenuous than leisure, agents still expend calories in their leisure time and the difference is not as pronounced to justify working as a weight loss strategy, especially for the majority of the population that is employed in sedentary occupations.

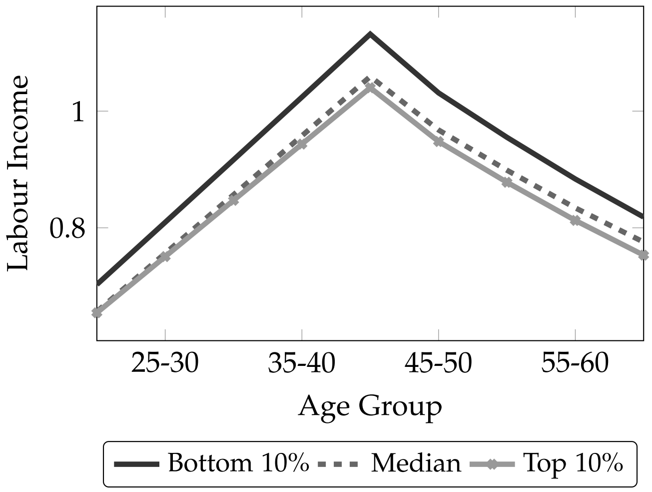
[37] The standard intra-temporal condition is described as $u_h = u_c \tilde{w} \left(1 - \tau^w\right)$, where u_h and u_c are the partial derivatives of the utility function with respect to labour supply and consumption respectively and $\tilde{w}$ is the effective wage rate. A lower effective wage rate, lowers labour supply and a lower level of consumption increases labour supply.

Figure 2.6: Simulation Results: Probability of Survival



Notes: Simulation Results for the bottom 10%, the median and the top 10% of the BMI distribution.

Figure 2.7: Simulation Results: Labour Income per Age as % of Per Capita GDP



Notes: Simulation Results for the bottom 10%, the median and the top 10% of the BMI distribution.

The relation between BMI and working hours has been studied extensively with a suggested positive correlation, however the direction of causality is assumed to be the reverse compared to our results. Au, Hauck and Hollingsworth (2013) surveyed metro transit workers with respect to their BMI, working hours and eating habits. They find a positive correlation between BMI and working hours, however the relation between eating habits and working hours is unclear. Working more than 50 hours per week is positively correlated with higher frequency of purchases from vending machines, however working hours were uncorrelated with consuming fast food, sweetened beverages and sweets or the perception of ease of eating healthily. On the contrary, the frequency of eating fruits and vegetables was positively correlated with working hours. On the other hand, the results of Escoto et al. (2010) suggest that working hours are associated with a greater pace of weight gain, studying a sample of Australian women.

We consider our result as an additional explanation for the positive correlation between working hours and BMI which needs further empirical investigation. It is possible that poorer individuals work longer hours in order to increase their consumption and at the same time exhibit bad eating habits because of time constraints to prepare food at home, which reinforces the positive correlation.

2.4.2 BMI and Inequality

The socio-economic gradient of obesity in developed countries is well-documented (Baum and Ruhm, 2009). Higher discounting (Courtemanche, Heutel and Mcalvanah, 2015), hyperbolic discounting (Ikeda, Kang and Ohtake, 2010), discrimination (Dackehag, Gerdtham and Nordin, 2014) and confounding factors such as genetics have been suggested in order to shed light on the relationship between socio-economic status and obesity. The study of the relation between BMI and inequality is fundamental in assessing the consequences of government intervention, since policies that target the obesity epidemic are more likely to affect the lower percentiles of the income distribution.

In order to assess the presence and magnitude of income and wealth inequality caused by obesity in our model, we calculate the respective Gini coefficients. However, since the model has a life-cycle aspect which is well known to cause income and wealth inequality by its nature, we estimate the counterfactual Gini coefficients of the same model without any intragenerational heterogeneity[38].

TABLE 2.5: GINI COEFFICIENTS

	Wealth	Labour Income	Net Income
Benchmark	52.99	8.71	23.96
Exogenous Productivity	52.51	8.37	23.49
No Heterogeneity	51.63	7.95	23.41
Data	73.2	N/A	34

In Table 2.5 we present the wealth, labour income and net income[39] Gini coefficients for our benchmark model, the model where we treat labour productivity as exogenous and not conditional on BMI, and the counter-factual model where there is no intragenerational heterogeneity and compare them with the UK data. We observe that even with no intragenerational heterogeneity[40] the wealth and net income Gini coefficient are 51.63% and 23.41% explaining a significant part of the UK inequality (70.5% and 68.9% of the observed inequality in the UK respectively).

In our benchmark model, the wealth, labour income and net income Gini coefficients increase substantially[41] by 1.36, 0.76 and 0.55 percentage points respectively compared to the counter-factual simulation. The difference between these two simulation results is the share of inequality that can be explained by the adverse effects of obesity on

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[38] Even in a two-period model with no intragenerational heterogeneity, in which agents supply labour in the first period, both labour income and savings are higher in the first period, resulting in income and wealth inequality. This level of inequality captures the different stages of life of the agents.

[39] Net income is defined as after tax payments and benefits receipts

[40] We estimate the Gini coefficients of a model where agents start with the same level of BMI, have the same preferences over food consumption and their occupation is equally strenuous for all agents. In essence, there is a single agent entering the economy every period and all the observed inequality can be explained by intergenerational differences.

[41] For context, the biggest increase of the Gini coefficient in the recent British history between 1979 to 1991 was 9 percentage points (Cribb et al., 2017). The impact of obesity on wealth inequality is 15% of that period's increase in inequality.

labour income and capital income as described in the previous section (Figures 2.5 & 2.7).

What are the sources of these adverse effects? In our model this relationship is straightforward; a higher level of BMI is causing a significant reduction in labour and capital income via lower productivity and a higher effective discount rate. In order to disentangle the effects of lower productivity and the higher discount rate, we estimate the Gini coefficients for the model with exogenous labour productivity, treating only the effective discount rate as endogenous. We find that the wealth, labour income and net income Gini coefficient are 52.51%, 8.37% and 23.49% respectively, which implies that the higher effective discount rate of obese agents can explain 65%, 58% and 15% of the inequality caused by obesity, which underlines the significance of the effective discount rate for the observed level of inequality.

The key difference with the results in the literature is that in order to generate the observe relation between income and BMI, no additional assumptions need to be made with respect to preferences or market structure. Endogeneizing life expectancy is sufficient to generate substantial inequality without hyperbolic discounting (Ikeda, Kang and Ohtake, 2010), non-separable utility function[42] , discrimination in the labour market (Dackehag, Gerdtham and Nordin, 2014) or ad hoc, exogenous differences with respect to the discount rate. In our model, the higher discount rate of obese agents is determined endogenously and the sole driver is the lower life expectancy.

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[42] Lakdawalla and Philipson (2009) postulate a non-monotonic relationship between income and BMI with income affecting the level of BMI. In their model, consumption and the utility derived from the level of weight are complements which can result to the cross derivative of the utility function with respect to consumption and the level of BMI to have a non-constant sign. This is not the case in our model since the the utility function is separable in all of its arguments and the cross derivatives are zero.

2.4.3 Net Life-Time Contributions

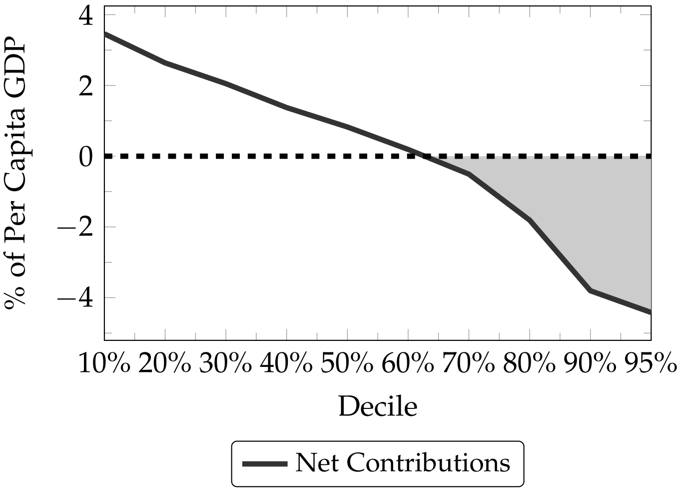
Estimating the net life-time contributions of each demographic is crucial for economic policy because, at least from an economist's perspective, government intervention cannot be justified unless there is an economic externality or the allocation is not Pareto optimal. The contribution of this paper is to provide a framework to analyze these questions in a quantitative general equilibrium model that is suitable for welfare analysis and estimating what is the true economic cost of obesity, taking into account life-time net contributions of the agents.

We define the net life-time contributions as the sum of all taxes paid throughout the individuals' life-time minus the life-time benefits, namely pensions, health care spending provided by the NHS and per capita government consumption. In order to make the exercise tractable, we partition the BMI distribution into the respective percentiles according to the initial level of BMI, hence an individual who starts at the bottom 10% of the BMI distribution will belong to the bottom group for this accounting exercise. This is a sensible assumption to make given that agents, as explained above, although they may switch between BMI classifications, they do not switch between the the percentiles of the BMI distribution in our model. Furthermore, we take into account the population mass of each percentile over time and thus we account for life-expectancy differentials. Hence, individuals of type i will have life-time net benefits of:

$$NET_t^i = \sum_{j=1}^{J} \psi_{i,j} \left(\tau^v w_t h_{j,t}^i + \tau^a r_t a_{j,t}^i + \tau^c c_{j,t}^i + \tau^f f_{j,t}^i \right) - \sum_{j=1}^{J} \psi_{i,j} \left(\tau^m m_{j,t}^i + b_t + g_t \right) \quad (2.26)$$

Figure 2.8 demonstrates the life-time net contributions for each percentile. The merit of this approach is that we can clearly assess the magnitude of the effect of obesity on the net contributions of the agents since the the net contributions of all agents as a percent of annualized GDP need to add up to zero.

Figure 2.8: Life-Time Net Contributions for Each Decile as a Percentage of per Capita GDP

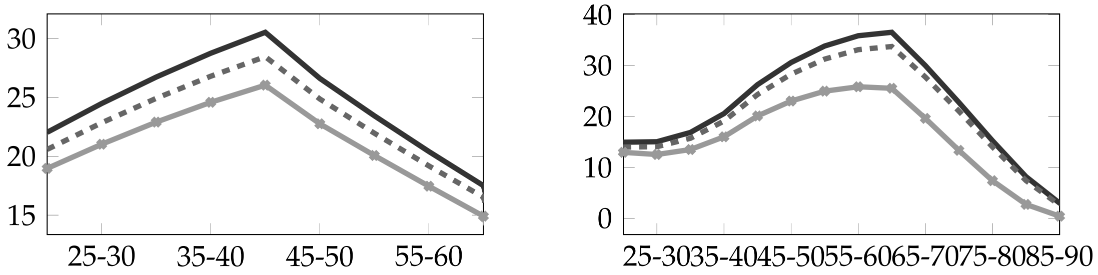


Notes: The net contribution of each decile of the BMI distribution is calculated as the life-time tax payment that finance pensions and health care subsidies minus the life-time pension receipts and subsidized medical spending. The results take into account the distinct mortality risk of each decile and are expressed in terms of annual per capita income.

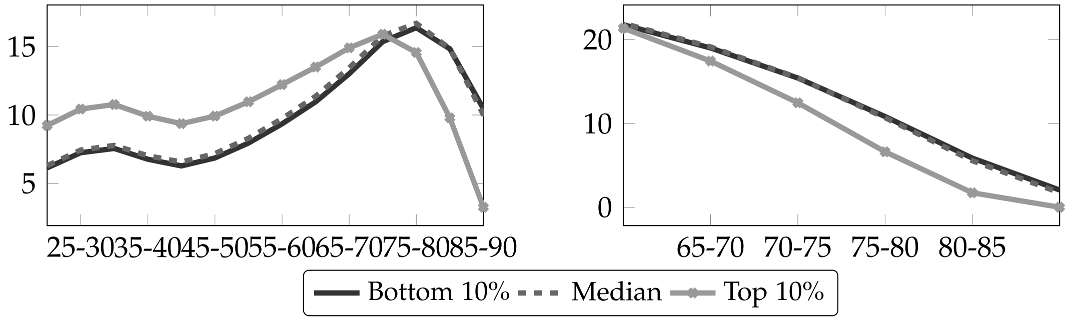
We observe that net life-time contributions fall monotonically with BMI, with the lower percentiles having positive and higher percentiles negative net contributions. The cut-off point is the bottom 60%, for which the net life-time contributions are essentially zero and agents receive in benefits as much as they contribute throughout their life-times. However, the differences between the percentiles are quantitatively small, with the top 95% of the BMI distribution having negative net contributions of 4.42% of annualized GDP per capita ($1933 in 2015). Hence, throughout their whole life-time, even morbidly obese individuals accumulate a deficit which is less than half of the average cost of a single elective inpatient stay incident in the NHS ($4736 (Curtis and Burns, 2016)).

Figures 2.9 & 2.10 demonstrate the life time contributions in greater detail and underline why ignoring the fact that obese individuals die prematurely can overestimate the

Figure 2.9: Labour Income Taxes, Medical Spending, Non-Labour Income Taxes and Total Benefits (Pensions and Medical Spending Subsidies) for Each Age Group


(a) Labour Income Taxes

(b) Non-Labour Income Taxes Per Age


(c) Medical Spending Per Age

(d) Total Pensions Age

Notes: Simulation Results for the bottom 10%, the median and the top 10% of the BMI distribution. The results take into account the distinct mortality risk of each decile and are expressed in terms of annual per capita GDP.

net cost of obesity. Even though both labour income and non-labour income taxes[43] are lower throughout the life-cycle for agents at the top of the BMI distribution, their net contributions are not substantially negative because the received benefits are lower than their healthy weight counter-parts after retirement (Figure 2.9) where their mortality rates diverge (Figure 2.6).

Figure 2.10 aggregates the net contribution with age. Agents have relatively low net contributions at the beginning of their life-time with higher percentiles of the BMI

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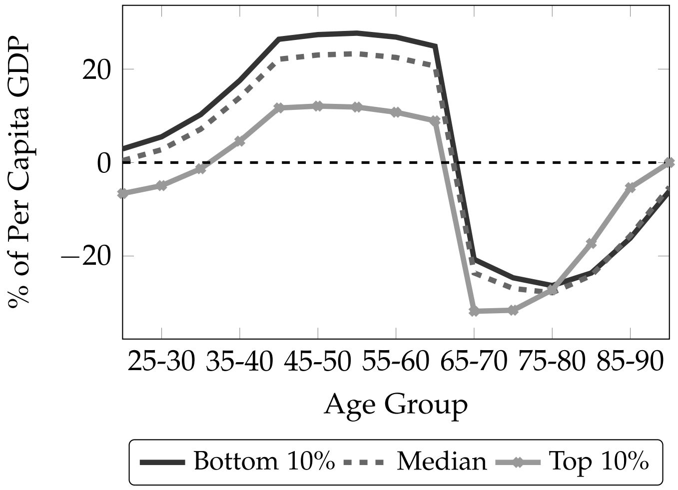
[43] Non labour income taxes consist of consumption taxes through the VAT, food consumption taxes and capital income taxes.

Figure 2.10: Life-Time Net Contributions for Age Group as a Percentage of per Capita Income



Notes: The net contribution of each percentile of the BMI distribution is calculated as the life-time tax payment that finance pensions and health care subsidies minus the life-time pension receipts and subsidized medical spending. The results take into account the distinct mortality risk of each decile and are expressed in terms of annual per capita income.

distribution having negative net contributions caused by excess medical spending. As agents age and before they reach the retirement age, their net contribution is increasing since agents accumulate more assets and their labour productivity is increasing and their tax contribution rises. Once agents reach the age of retirement, they stop paying labour income taxes, start decumulating assets and face higher medical spending due to the higher mortality risk caused by age and BMI, while receiving pensions. Naturally, as agents age their net contributions fall into negative territory, however, taking into account the population mass of each percentile of the BMI distribution, we observe that the burden of the obese is less than the healthy BMI percentiles at older ages.

2.5 Policy Experiments

The rising prevalence of obesity has stimulated a discussion with respect to policy interventions that can tackle the obesity epidemic. Apart from the economic externality of obesity, which as shown in the previous section is quantitatively small but not zero, government intervention can be justified on the grounds of Pareto optimality and public health concerns.

In this section we focus on two distinct government interventions, which are both policy relevant and have received considerable attention; (i) childhood obesity and (ii) taxing food consumption. Childhood obesity has instantaneous adverse effects on children, such as mental health (Pizzi and Vroman, 2013) and various co-morbidities (Jackson-Leach and Lobstein, 2006) but is also correlated with adult obesity (Nader et al., 2006). Hence tackling childhood obesity can have a positive welfare effect both for children and for future adults, increasing life expectancy, quality of life and labour productivity.

Taxing food consumption, in particular food categories that are associated with weight gain such as food rich in fat and sugar is another policy intervention that is being considered or already implemented in developed countries such as the UK and Denmark. Since we do not distinguish between food categories in our model, we are going to proxy a tax on these categories of food consumption by eliminating the VAT exemption on food consumption.

2.5.1 Eliminating Childhood Obesity

We assess what is the economic impact of tacking childhood obesity by a counterfactual simulation where we completely eliminate childhood obesity in our model. Although from a policy perspective this is not an achievable allocation, we consider this exercise useful for policy analysis since it demonstrates the upper bound of the potential welfare gains of such government intervention.

We simulate the elimination of childhood obesity by keeping the specification identical to the benchmark model described above, with the exception of the initial BMI that the agents 'inherit' and enter the economy. Hence, all the adults that are 'born' in our model, do so with a healthy BMI but continue to have different preferences with respect to food consumption and supply labour in occupations with different levels of strenuousness. This ensures that our results are comparable with our benchmark model and that we focus on the elimination of childhood obesity and not obesity overall. Adults can and in fact become, overweight and obese at rates which depend on their preferences and the strenuousness of their occupation.

We calculate the welfare losses or gains in terms of consumption equivalence, namely the percentage of the change in current consumption, in order to achieve the same level of utility as after the government intervention. For example, percentage change in today's consumption in order to achieve the same level of utility as after the policy change at $t+1$ in aggregate terms, namely the sum of all agents weighted by their population mass is the x such that:

$$\begin{aligned}&\sum_{j=1}^{J}\sum_{i=1}^{I}\psi_{j,t}^{i}u\left(\left(c_{j,t}^{i}\left(1+x\right),f_{j,t}^{i},l_{j,t}^{i},\Omega\left(W_{j,t}^{i}\right)\right)\right)-\\&-\sum_{j=1}^{J}\sum_{i=1}^{I}\psi_{j,t+1}^{i}u\left(\left(c_{j,t+1}^{i},f_{j,t+1}^{i},l_{j,t+1}^{i},\Omega\left(W_{j,t+1}^{i}\right)\right)\right)=0\end{aligned}\tag{2.27}$$

The merit of this approach is that we assess the overall impact of government interventions, in terms of consumption, food consumption, labour supply, quality of life through $\Omega\left(W_{j,t}^{i}\right)$ and endogenous life expectancy through the population mass $\psi_{j,t}^{i}$. Furthermore, since the utility function is concave with respect to consumption, we account for the fact that the effects of a policy intervention in terms of welfare are not uniform across demographics[44].

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[44] An increase in consumption by 10% does not have the same welfare implications for the

We find that the welfare implications of eliminating childhood obesity are substantial. At the aggregate level the increase in welfare is equivalent to an increase in consumption by 10.5%. All agents experience an increase in welfare, even the median agents whose characteristics did not change compared to the benchmark case earning the equivalent of 0.3% of consumption. The reason behind this result is the general equilibrium effect of reducing the prevalence of obesity. First, the NHS saves almost 1% of its budget ($1.48 bn) when we consider the lower bound of the effects of obesity on health care spending. Secondly, GDP increases by 2.15% compared to the benchmark case, due to an increase in labour productivity and savings, with the latter being affected by the lower effective discount rate.

At an individual level, the effects of eliminating childhood obesity are strongly heterogenous with higher percentiles of the BMI distribution benefiting the most. In fact, the top 5% of the BMI distribution experiences an increase in welfare which is equivalent to 47.5% of consumption. These agents experience significant welfare gains for five reasons; (i) lower medical spending, (ii) higher labour productivity, (iii) higher asset accumulation (iv) higher instantaneous utility since they are closer to their ideal weight and (v) more periods that they can derive utility from, caused by higher life expectancy. Agents at the top 5% of the BMI distribution at the age of 65 are expected to live 6 years longer than the benchmark case.

Furthermore, eliminating childhood obesity essentially eliminates the obesity externality, even though the prevalence of obesity is not eliminated. In fact, the net contributions for the higher percentiles of the BMI distribution are positive, while the net contributions of the lower percentiles are negative. However, the magnitude of both the positive and negative net contributions is reduced even further, since the economic burden of obesity is eliminated, the healthy BMI individuals do not need to subsidize the overweight and obese.

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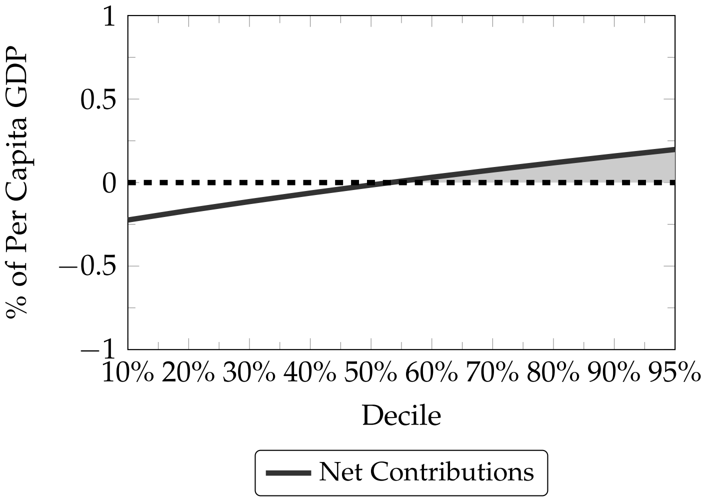
top and the bottom of the income distribution.

Figure 2.11: Life-Time Net Contributions After Eliminating ChildHood Obesity



Notes: The net contribution of each decile of the BMI distribution is calculated as the life-time tax payment that finance pensions and health care subsidies minus the life-time pension receipts and subsidized medical spending. The results take into account the distinct mortality risk of each decile and are expressed in terms of annual per capita income.

The reason for the negative net contributions of the lower percentiles lies in their life expectancy differentials that result in more periods of pension receipts. Higher percentiles still face higher medical spending and lower life expectancy compared to lower percentiles, however the reduction in medical spending is more than enough to compensate for the increase in pension payments towards this demographic and in fact, eliminate the obesity externality.

Hence, the potential welfare and economic gains from tackling the rising prevalence of childhood obesity are sizable. The cost of the NHS falls and GDP increases, while individuals experience an increase in welfare both because of the economic benefits of a less burdensome obesity prevalence and the increase in quality of life and life expectancy.

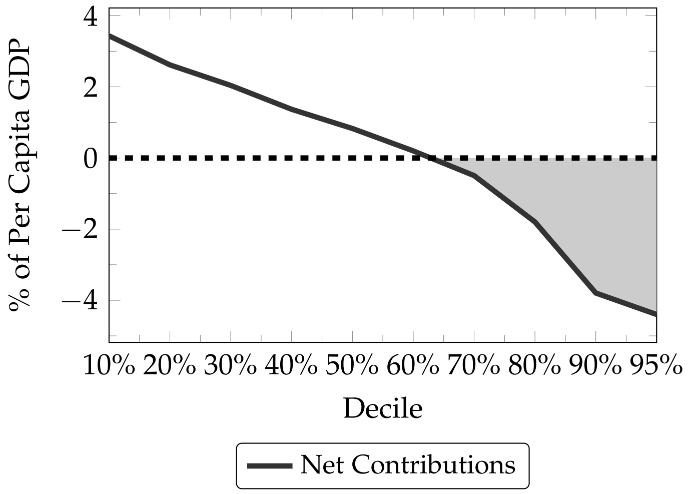
2.5.2 Eliminating the VAT Exemption on Food Consumption

Since we do not distinguish between food categories, we cannot assess the macroeconomic affects of taxes on specific goods, such as the soda or fat tax. However, we can assess the effect of eliminating the VAT exemption on specific food products, as described in the previous section. Given the share of food consumption towards goods that are exempt from VAT and food consumption that faces a VAT of 20%, we estimated that the effective VAT on food consumption is 9.7%. For this exercise, we consider the effect of taxing all food consumption with a VAT of 20%, hence increasing the effective VAT from 9.7% to 20%, while the rest of the parameterization remains constant.

At the aggregate level, eliminating the exemptions on food consumption has a positive welfare effect equivalent to 0.26%. However, the improvement is not Pareto optimal as the case of eliminating childhood obesity and the aggregate result conceals a lot of variation between demographics. We obtain the counterintuitive result of a reduction in welfare for the bottom 20% of the BMI distribution and an increase in welfare for the rest of the percentiles. Quantitatively, the magnitude of the welfare gains and losses is not as great as the case of eliminating childhood obesity, however the losses for the bottom 10% are 0.41% of consumption and the gains for the top 5% are equivalent to 0.6% of consumption.

Higher percentiles of the BMI distribution experience welfare gains for two reasons; first, an increase in the VAT of food consumptions distorts their behaviour, leading to a slower pace of weight gain with subsequent positive effects on labour productivity, asset accumulation and utility from the level of BMI. Secondly, an increase in the VAT of food consumption reduces the labour income tax. Recall that the labour income tax acts as a residual that balances the government budget. In a nutshell, an increase in the VAT is equivalent to transferring a part of revenue resources from labour income taxation to food consumption taxation. This has significant implication on the financing of the government budget because of the life expectancy differentials. Until the age of 65, the mortality rate is low for all demographics and hence both obese and non-obese finance government spending through labour income taxes, however at higher ages both the mortality rate and the mortality differentials increase, less obese individuals are contributing through capital income, general consumption and food consumption taxes. By transferring the burden of financing the government budget from a tax that has to be paid until the age of 65 to a tax that is paid throughout the whole life-time, the government puts additional pressure on percentiles that have higher life-expectancy.

Figure 2.12: Life-Time Net Contributions After Eliminating the vat Exemption



Notes: The net contribution of each decile of the BMI distribution is calculated as the life-time tax payment that finance pensions and health care subsidies minus the life-time pension receipts and subsidized medical spending. The results take into account the distinct mortality risk of each decile and are expressed in terms of annual per capita income.

Since the magnitude of the VAT change is not large, the quantitative effect of this policy at a macroeconomic level are expected to be small. Life expectancy for the higher percentiles increases by approximately one month for all age groups, while the NHS saves a 0.16% of its budget ($0.26 bn). With respect to the response of labour supply with an increase in VAT and a decrease the labour income tax, we observe a consistent pattern across all BMI percentiles. Labour supply decreases by as much as 0.29% at the age of 20 and increases as much as 0.37% at the age of 65. We find that the income effect dominates the substitution effect earlier in the life-cycle, but labour supply increases at older ages since agents are more productive compared to the benchmark case. GDP increases by 0.27% after the elimination of VAT exemption, which affects the labour supply decisions of the agents. However, the increase in GDP is not attributed to changes in labour supply, since the aggregate hours of work do not change in our model, with the decrease during earlier periods being offset by the increase in later periods of life. The main drivers of the GDP increase are higher savings caused by the lower effective discount rate, higher labour productivity caused by a reduction in average BMI and lower health care spending. Finally, the net contributions of the percentile changes only slightly with the deficit of the top 5% of the BMI distribution being 4.39% instead of 4.42% of annualized per capita GDP (Figure 2.12).

Hence, although at the aggregate level we observe that taxing food consumption more heavily has positive welfare implications, the intervention is not Pareto improving. As long as the goal of the government is to eliminate the economic externalities caused by the obesity epidemic, increasing the VAT on food consumption has the opposite effect on the lower percentiles of the BMI that have a net surplus of contributions. This observation underlines the peculiarities of the prevalence of obesity in contrast to other health hazards such as smoking, since food consumption is a basic need for all individuals, and any policies that target food consumption affect all the percentiles of the BMI distribution, even the healthy ones.

2.6 Sensitivity Analysis

In this section we perform robustness analysis on fundamental assumptions of our model for two reasons; (i) to test the sensitivity of the results of the benchmark model and (ii) to examine the main driving forces of the obesity prevalence and the obesity externality. The model in this paper has many features and the evolution of BMI and it's subsequent effects on life expectancy, labour productivity and welfare can be decomposed in different parts. This section assesses their significance.

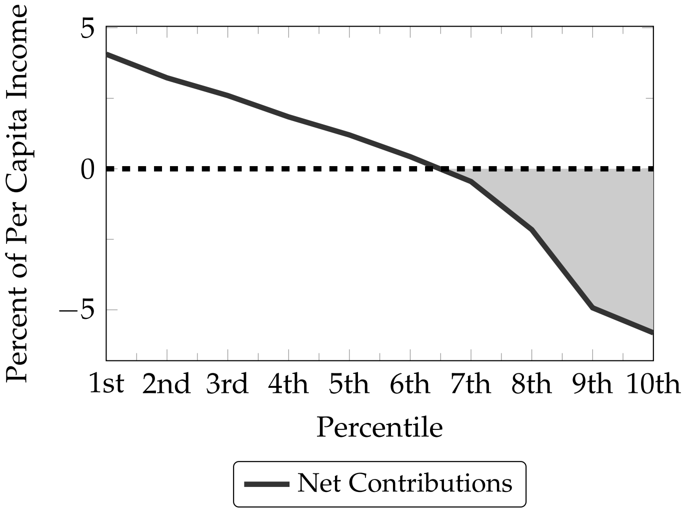
We estimate the model with the upper bound of medical spending caused by obesity, as estimated in section 1.3, the model where labour productivity is exogenous and does not depend on BMI and a model where preferences are uniform with respect to food consumption across all demographics.

2.6.1 Upper Bound of Medical Spending

The results of the benchmark simulation suggest that the obesity externality is quantitatively small. Here, we assess what is the magnitude of this externality if we consider the upper bound of the medical spending caused by obesity, by re-estimating the model in order reach a cost of obesity equal to 14.56% of the NHS budget, more than double compared to the benchmark simulation of 6.3%.

We find that the net contribution deficit of the higher percentiles of the BMI distribution increases from 4.42% to 5.81% of annualized per capita GDP (from \$1933 to \$2540 in 2015). The shape of the curve remains the same, with lower percentiles having positive net contributions and higher percentiles having negative contributions (Figure 2.13). The difference compared to the benchmark model is that the curve is now steeper and the cut-off point of the net contributions is past the bottom 60%.

Figure 2.13: Upper Bound of Medical Spending:Life-Time Net Contributions for Each Decile as a Percentage of per Capita GDP



Notes: The net contribution of each decile of the BMI distribution is calculated as the life-time tax payment that finance pensions and health care subsidies minus the life-time pension receipts and subsidized medical spending. The results take into account the distinct mortality risk of each decile and are expressed in terms of annual per capita income.

Even though the burden of obese individuals on the NHS is substantially higher[45] (Figure 2.14), the overall impact of obesity does not increase by a sizable amount. This result underlines the importance of the general equilibrium framework in order to analyze the fiscal impact of obesity; even when we consider the upper bound of the medical cost of obesity, the overall externality is quantitatively small compared to the life-time contributions and social security benefits through the pay-as-you-go scheme.

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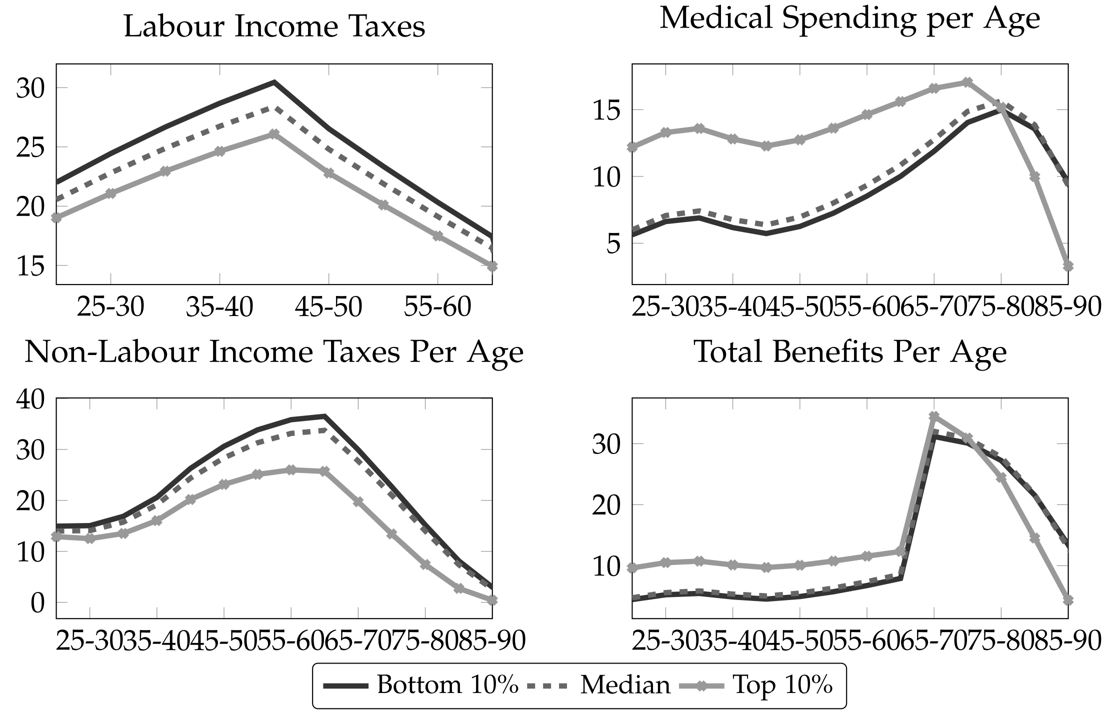
[45] For example at the age of 20-25 an individual at the 5% of the BMI distribution spends 9.23% of annualized GDP on health care in the benchmark model compared to the counterfactual of 12.18%.

Figure 2.14: Upper Bound of Medical Spending:Labour Income Taxes, Medical Spending, Non-Labour Income Taxes and Total Benefits (Pensions and Medical Spending Subsidies) for Each Age Group

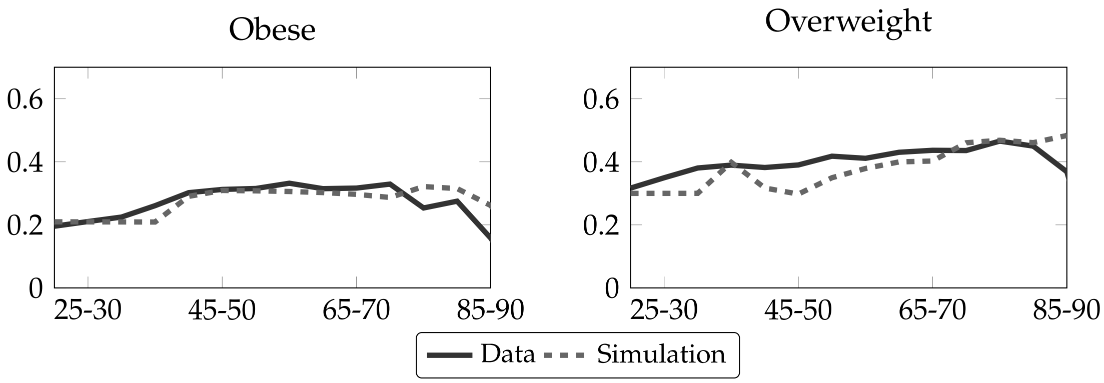


Notes: Simulation Results for the bottom 10%, the median and the top 10% of the BMI distribution. The results take into account the distinct mortality risk of each decile and are expressed in terms of annual per capita GDP.

Considering the upper bound of the medical cost of obesity has consequences beyond the estimation of the net contributions of the BMI distribution. Since our model is a general equilibrium model and agents take into account the effects of food consumption on the level of BMI and its subsequent effects on medical spending, the marginal increase of the net deficit of the higher BMI percentiles might be attributed to the different allocation. Namely, agents will now weight their food consumption differently, once they take into account the effects of BMI on medical spending. Recall that medical spending is an out-of-pocket payment that has to be paid in order to survive to the next period and only a fraction is subsidized by the government.

Figure 2.15 shows that this is not the case and our results are comparable with the benchmark model. The distribution of obese and overweight individuals tracks closely the distribution as observed in the data and it's indistinguishable from the benchmark model. Hence, the results are not affected by the choice of the agents to consume less food and achieve a lower level of BMI because it is now too costly to be overweight.

Figure 2.15: Upper Bound of Medical Spending:Percentage of Obese and Overweight by Age Group



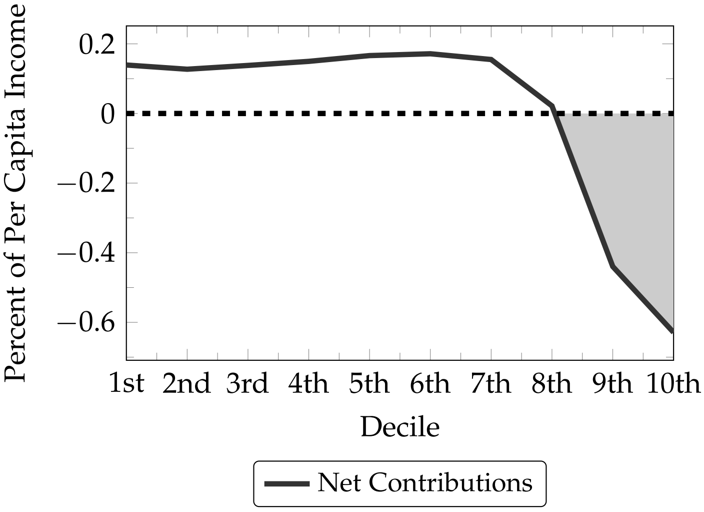
Notes: Data are obtained from the Health Survey for England (2011-14). The simulation results are the weighted average BMI of each age group.

2.6.2 Exogenous Labour Productivity

Treating labour productivity as strictly exogenous has important implications in our model. The net contributions deficit of the higher percentiles of the BMI distribution is practically eliminated, from 4.42% as a percentage of annualized per capita GDO in the benchmark case to 0.63% (from $1933 to $276) (Figure 2.16).

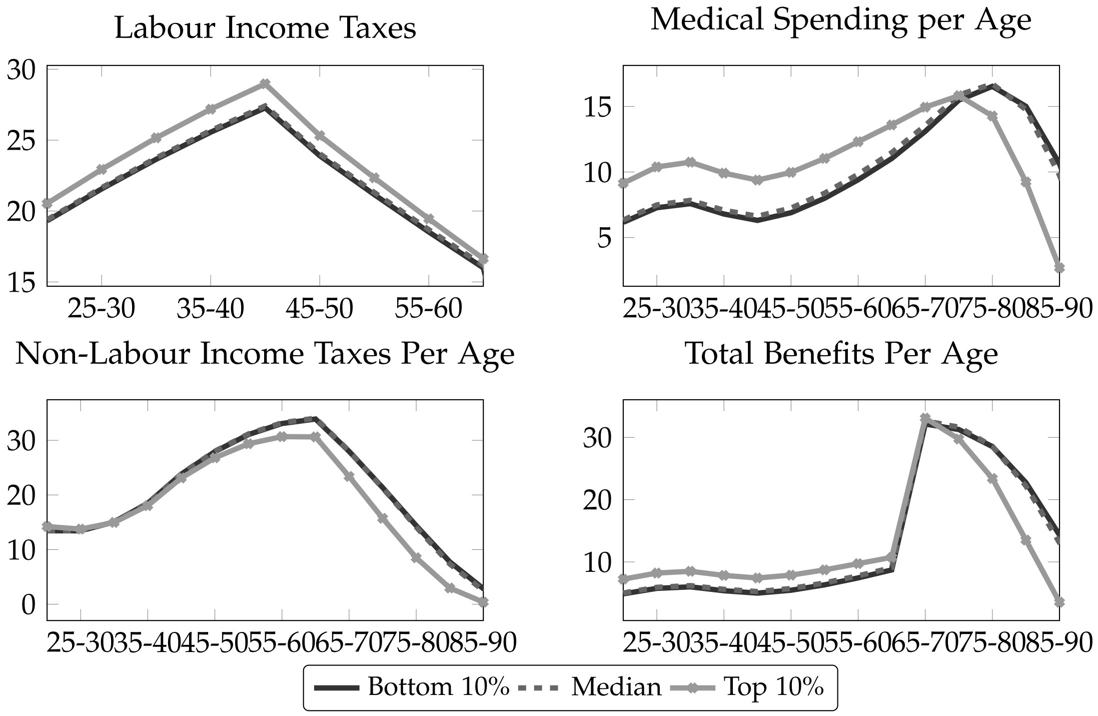
This is an important result because it reveals that the source of the net deficit with respect to life-time contributions for obese agents comes from the lower level of contributions, rather than excess medical spending. Net contributions are still negative for the top 20%, but despite the excess burden on the NHS, their life-time contributions and premature mortality roughly offset the received benefits. In fact, although the non-labour income taxes are lower for the top percentiles of the BMI distribution for the majority of their life-cycle, labour income taxes are higher (Figure 2.17).

Figure 2.16: Exogenous Labour Productivity:Life-Time Net Contributions for Each Decile as a Percentage of per Capita GDP



Notes: The net contribution of each decile of the BMI distribution is calculated as the life-time tax payment that finance pensions and health care subsidies minus the life-time pension receipts and subsidized medical spending. The results take into account the distinct mortality risk of each decile and are expressed in terms of annual per capita income.

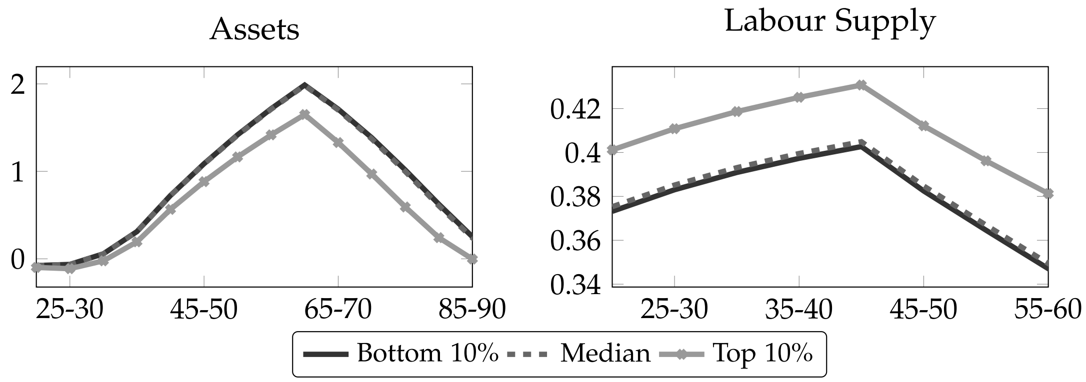
Figure 2.17: Exogenous Labour Productivity:Labour Income Taxes, Medical Spending, Non-Labour Income Taxes and Total Benefits (Pensions and Medical Spending Subsidies) for Each Age Group



Notes: Simulation Results for the bottom 10%, the median and the top 10% of the BMI distribution. The results take into account the distinct mortality risk of each decile and are expressed in terms of annual per capita GDP.

This is because the income effect as described in the previous section still induces obese agents to supply more labour (Figure 2.18), however their hourly wage is on par with healthy weight individuals resulting in higher labour income and higher labour income taxes. The source of their income effect, namely the source of their lower overall disposable income is the lower level of assets, which results in lower level of capital income and higher medical spending.

FIGURE 2.18: EXOGENOUS LABOUR PRODUCTIVITY:SIMULATION RESULTS: SAVINGS AND LABOUR SUPPLY



Notes: Simulation Results for the bottom 10%, the median and the top 10% of the BMI distribution.

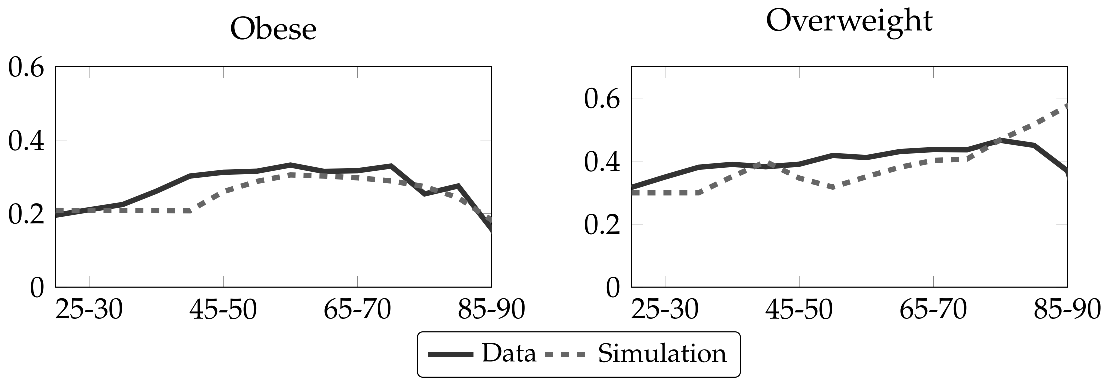
Hence our results are sensitive to the specification of the relation between BMI and productivity and demonstrate that unless obese agents are substantially poorer because of obesity, the net economic cost of obesity is essentially eliminated.

2.6.3 Uniform Preferences

Although there are strong evidence that support that genetic differences are responsible for a significant fraction of the observed rise in obesity (see inter alia Waalen (2005), Elks et al. (2012); Haworth et al. (2008)), for sensitivity analysis we perform a counter-factual simulation where preferences are uniform with respect to food consumption.

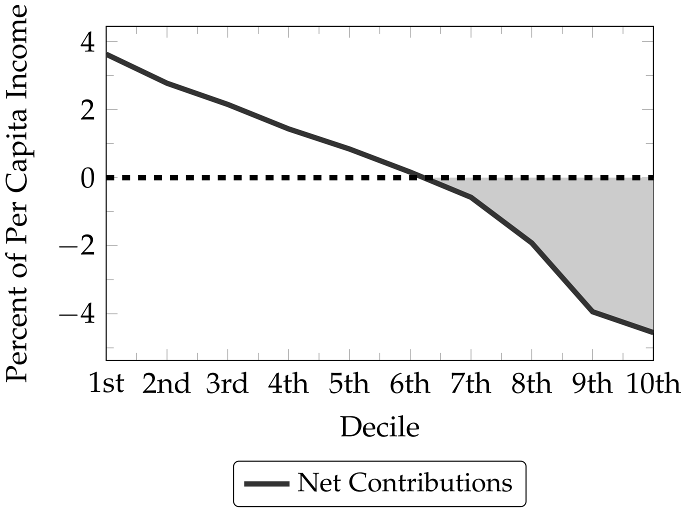
Our results hold both qualitatively and quantitative, however the model keeps track of the prevalence of obesity at older ages (even better than the benchmark model) but not as close at younger ones (Figure 2.19). Quantitatively, the results still hold and we can be confident that are no driven by ad hoc differences in preferences between the agents (Figures 2.20 & 2.21).

Figure 2.19: Uniform Preferences:Percentage of Obese and Overweight by Age Group



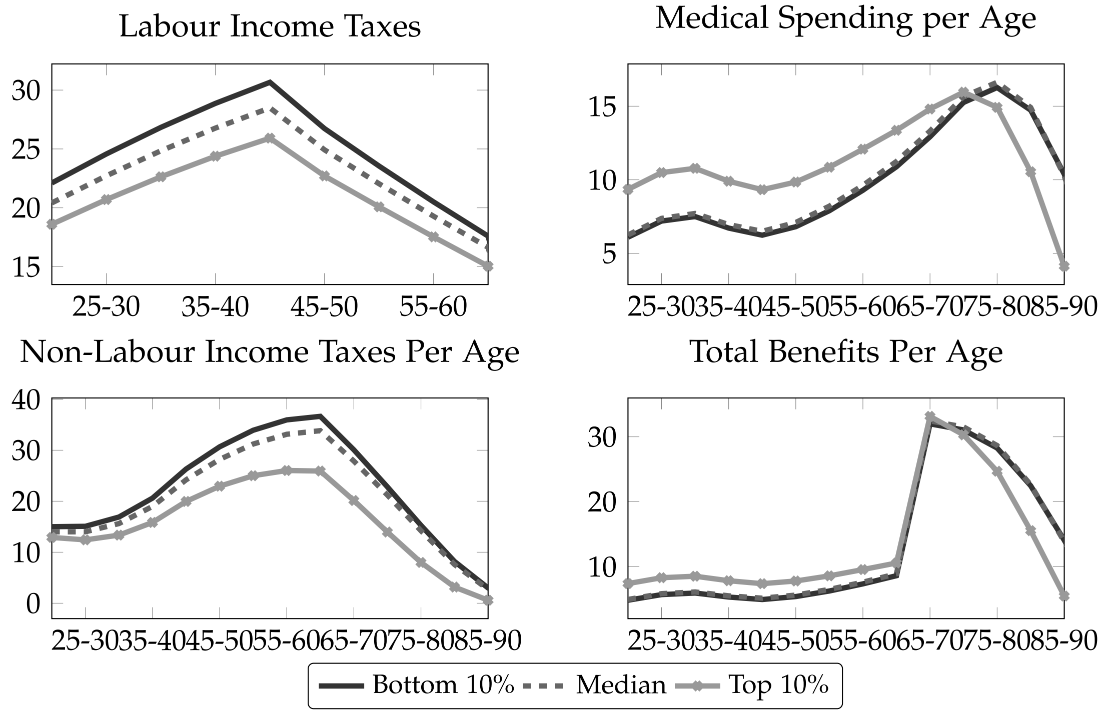
Notes: Data are obtained from the Health Survey for England (2011-14). The simulation results are the weighted average BMI of each age group.

Figure 2.20: Uniform Preferences:Life-Time Net Contributions for Each Decile as a Percentage of per Capita GDP



Notes: The net contribution of each decile of the BMI distribution is calculated as the life-time tax payment that finance pensions and health care subsidies minus the life-time pension receipts and subsidized medical spending. The results take into account the distinct mortality risk of each decile and are expressed in terms of annual per capita income.

FIGURE 2.21: UNIFORM PREFERENCES:LABOUR INCOME TAXES, MEDICAL SPENDING, NON-LABOUR INCOME TAXES AND TOTAL BENEFITS (PENSIONS AND MEDICAL SPENDING SUBSIDIES) FOR EACH AGE GROUP



Notes: Simulation Results for the bottom 10%, the median and the top 10% of the BMI distribution. The results take into account the distinct mortality risk of each decile and are expressed in terms of annual per capita GDP.

2.7 Conclusions

This paper studies the fiscal and welfare implication of obesity in a model where (i) food consumption and weight (ii) labour productivity (iii) life expectancy and (iv) medical spending are endogenous. Our aim is to, first, replicate key moments of the UK economy and assess the presence and magnitude of externalities associated with obesity and secondly, to perform policy experiments in order to quantify the economic and welfare implications of changes in government policy.

Our results suggest that the magnitude of the obesity externality is quantitatively small, since the life-time net contributions deficit of obese individuals is up to 5.81% of annualized per capita GDP, despite the significant effects of obesity on income inequality and the subsequent effect on the level of contributions. We find that the lion's share of the net deficit is not accumulated due to excess medical spending of the obese individuals, but from their lower level of contributions caused by lower labour productivity and the lower level of asset accumulation, because of the higher discount factor.

Furthermore, our results show that government intervention with respect to childhood obesity and food taxation can have substantial welfare and economic implications, however the latter is not Pareto improving. Both policies reduce the level of the NHS spending and increase the level of GDP because of higher capital accumulation and labour productivity and have significant implications for life expectancy and quality of life, especially for obese individuals. However, we find that if the goal of the government intervention is to eliminate the obesity externality, and hence healthy weight individuals do not subsidize the higher percentiles of the BMI distribution, the increase in the VAT on food consumption has the opposite effect. Healthy weight individuals experience losses with respect to their level of life-time welfare, which is the outcome of food consumption being a basic human need and only excess calorie expenditure does it has adverse effects on the individuals. Hence, any policies targeted towards food consumption affect all individuals.

The model could be extended in various directions. First, in this paper we abstract from the allocation of leisure time and in particular exercise, which plays a role in the accumulation of excess weight. Secondly, we do not distinguish between various food categories, both with respect to price and calorie density. We anticipate that the allocation of food expenditure between different categories, and its relation to the level of disposable income can have significant welfare implications when considering government interventions. For example, targeting specific food categories that are cheap and calorie dense, may be consumed more by poorer individuals. Finally, we do not consider the effects of uncertainty in our model, both on labour income and unanticipated health shocks which could influence the optimal allocation of the households. We leave these issues for future research. Furthermore, the introduction of endogenous retirement can enrich the model and estimate contributions more accurately. Although we allow for adjustments in the intensive margin of labour supply, we do not allow for adjustments in the extensive margin, namely premature retiment or postponement of the retirement after the retirement age.

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Appendix

2.A First Order Conditions

Here I present the first order conditions of the household with respect to general consumption, food consumption and labour supply in order to demonstrate the objectives of the agents. For clarity, I drop the time notation and I will denote u_{j,c_j} as the partial derivative of the utility function at period j with respect to consumption at period j. Let λ_j denote the Lagrange multiplier at period j. For clarity of exposition I demonstrate a 3-period model. The first order condition of the household with respect to consumption in periods 1, 2 and 3 respectively are denoted as:

$$u_{1,c_1} - \lambda_1 \left(1 + \tau^c\right) = 0 \quad \forall t \tag{2.A.1}$$

$$\beta P_2 \left(W_{1,t}\right) u_{2,c_2} - \lambda_2 \left(1 + \tau^c\right) = 0 \quad \forall t \tag{2.A.2}$$

$$\beta^2 P_3 \left(W_2\right) u_{3,c_3} - \lambda_3 \left(1 + \tau^c\right) = 0 \quad \forall t \tag{2.A.3}$$

However, the decision of the agent with respect to food consumption and labour supply is not as straightforward. Agents decide their level of food consumption taking into account the direct effect of food consumption on the current period's utility, the effect of food on BMI, and the subsequent indirect effect on utility, labour productivity, probability of survival and medical spending. Moreover, since the decision of food consumption today affects the level of BMI of the next period, agents take into account the effects of today's food consumption on next period's BMI. Hence, agents face different incentives throughout their lifetime; from the $J = 1$ until $J_R - 1$ agents take into account not only next period's level of utility and medical spending, but also the effects of BMI on next period's labour productivity. At age J_R, the agents' last working period, there is no effect on next period's productivity since the agent retires and she takes into account only the effects of BMI on utility, the probability of survival and medical spending. At age J, the agent dies with certainty and current decisions have no effect on future variables.

Hence during the first period of life, the optimal decision with respect to food consumption is denoted as:

$$\begin{aligned}
&u_{1,f_1} + \Omega_{1,W_1} W_{1,f_1} + \beta P_{1,W_1} W_{1,f_1} u_2 \left(c_2, f_2, h_2, \Omega_2\right) + \\
&+\beta P_1 \left(W_1\right) \left(\Omega_{2,f_1} W_{2,f_1}\right) + \\
&+\lambda_1 \left(1-\tau^w\right) w h_1 \varepsilon_{W_1} W_{1,f_1} + \lambda_2 \left(1-\tau^w\right) w h_2 \varepsilon_{W_2} W_{2,f_1} - \\
&-\lambda_1 \left(1+\tau^m\right) m_{1,W_1} W_{1,f_1} - \lambda_2 \left(1+\tau^m\right) m_{2,W_2} W_{2,f_1} - \\
&-\lambda_1 \left(1+\tau^f\right) = 0
\end{aligned} \tag{2.A.4}$$

At period 2, the agent expects that she will retire, and thus she doesn't take into account the effect of food consumption on next period's productivity:

$$\begin{aligned}
&\beta P_1 \left(W_1\right) u_{1,f_1} + \beta P_1 \left(W_1\right) \Omega_{2,W_2} W_{2,f_2} + \beta^2 P_{2,W_3} W_{3,f_2} u_3 \left(c_3, f_3, h_3, \Omega_3\right) + \\
&+\beta^2 P_2 \left(W_2\right) \left(\Omega_{3,f_2} W_{3,f_2}\right) + \\
&+\lambda_2 \left(1-\tau^w\right) w h_2 \varepsilon_{W_2} W_{2,f_2} - \\
&-\lambda_2 \left(1+\tau^m\right) m_{2,W_2} W_{2,f_2} - \lambda_3 \left(1+\tau^m\right) m_{3,W_3} W_{3,f_2} - \\
&-\lambda_2 \left(1+\tau^f\right) = 0
\end{aligned} \tag{2.A.5}$$

Finally, during the last period of life, the agent takes into account only the effects of food consumption on current utility and BMI:

$$\begin{aligned}&\beta^2 P_2\left(W_2\right) u_{3,f_3}+\beta^2 P_2\left(W_2\right) \Omega_{3,W_3} W_{3,f_3}\\&-\lambda_3\left(1+\tau^m\right) m_{3,W_3} W_{3,f_3}-\lambda_2\left(1+\tau^f\right)=0\end{aligned} \tag{2.A.6}$$

Equivalently, the labour supply decision of the agent takes into account the effects of labour supply on BMI and the indirect effects as discussed above. Thus, the first order condition with respect to labour supply for the first period is denoted as:

$$\begin{aligned}&u_{1,h_1}+\Omega_{1,W_1} W_{1,h_1}+\beta P_{1,W_1} W_{1,h_1} u_2\left(c_2, f_2, h_2, \Omega_2\right)+\\&+\beta P_1\left(W_1\right)\left(\Omega_{2,W_2} W_{2,h_1}\right)+\\&+\lambda_1\left(1-\tau^w\right) w h_1 \varepsilon_{W_1} W_{1,h_1}+\lambda_1\left(1-\tau^w\right) w \varepsilon\left(W_1\right)\\&+\lambda_2\left(1-\tau^w\right) w h_2 \varepsilon_{W_2} W_{2,h_1}-\\&-\lambda_1\left(1+\tau^m\right) m_{1,W_1} W_{1,h_1}-\lambda_2\left(1+\tau^m\right) m_{2,W_2} W_{2,h_1}=0\end{aligned} \tag{2.A.7}$$

And for the second period:

$$\begin{aligned}&\beta P_1\left(W_1\right) u_{2,h_1}+\beta P_1\left(W_1\right) \Omega_{2,W_2} W_{2,h_2}+\beta^2 P_{2,W_2} W_{2,h_2} u_3\left(c_3, f_3, h_3, \Omega_3\right)+\\&+\beta^2 P_2\left(W_2\right)\left(\Omega_{3,W_3} W_{3,h_2}\right)+\\&+\lambda_2\left(1-\tau^w\right) w h_2 \varepsilon_{W_2} W_{2,h_2}+\lambda_2\left(1-\tau^w\right) w \varepsilon\left(W_2\right)\\&-\lambda_1\left(1+\tau^m\right) m_{2,W_2} W_{2,h_2}-\lambda_3\left(1+\tau^m\right) m_{3,W_3} W_{3,h_2}=0\end{aligned} \tag{2.A.8}$$

2.B Tables

Table 2.B.2: Calibration Parameters

Parameter		Value	Target
Demographics			
Retirement Age:	J_R	9	By assumption
Maximum Age:	J	15	By assumption
Population Growth:	n	0.03	Data
Mortality Rate	Φ	Human Mortality Database	Data
Preferences			
CRRA Consumption:	γ	2	Conesa et al. (2009)
CRRA Food:	σ	2	By assumption
CRRA Labour Supply:	η	3	Conesa et al. (2009)
Pref. Par. Labour:	ν	1	$L = 0.3$
Pref. Par. Food:	ϕ	0.01-0.02	$F/C = 0.12$
Technology			
Capital Share:	α	0.33	Data
Depreciation:	δ	0.07	Data
Endog. Productivity:	ζ	0.01	Own Calculations
Government			
Consumption Tax:	τ^c	0.2	Data
Capital Income Tax:	τ^r	0.46	Uhlig
Food Consumption Tax:	τ^f	0.097	Own Calculations
NHS Share of Health Care Spend. :	τ^m	0.83	Data
Pension Replacement Rate:	χ	0.335	Data

Table 2.B.1: Regression Results

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
BMI	0.272***	0.275***	0.240***	0.240***	-0.137**	-0.135**	-0.127**	-0.128**
	(3.81)	(3.85)	(3.36)	(3.37)	(-3.02)	(-2.97)	(-2.80)	(-2.80)
BMI Squared	-0.00492***	-0.00497***	-0.00455***	-0.00456***	0.00233**	0.00229**	0.00220**	0.00220**
	(-4.26)	(-4.30)	(-3.94)	(-3.95)	(3.17)	(3.12)	(3.00)	(3.00)
Age	-0.123***	-0.125***	-0.113***	-0.113***	0.0336*	0.0339*	0.0325*	0.0323*
	(-5.54)	(-5.65)	(-5.11)	(-5.11)	(2.41)	(2.43)	(2.33)	(2.32)
Age Squared	0.00190***	0.00188***	0.00169***	0.00169***	-0.000566***	-0.000594***	-0.000566***	-0.000564*
	(9.18)	(9.07)	(8.13)	(8.13)	(-4.27)	(-4.46)	(-4.24)	(-4.22)
Married	1.952***	2.074***	1.867***	1.862***	-0.206	-0.144	-0.110	-0.107
	(10.67)	(10.89)	(9.77)	(9.73)	(-1.76)	(-1.19)	(-0.91)	(-0.88)
Separated	0.000716	0.0849	0.0947	0.0949	0.711**	0.751**	0.749**	0.748**
	(0.00)	(0.15)	(0.16)	(0.16)	(2.82)	(2.97)	(2.97)	(2.96)
Divorced	0.0746	0.157	0.168	0.167	0.260	0.296	0.291	0.293
	(0.25)	(0.52)	(0.56)	(0.55)	(1.55)	(1.75)	(1.73)	(1.74)
Widowed	0.455	0.540*	0.512	0.511	-0.0883	-0.0248	-0.0234	-0.0247
	(1.67)	(1.96)	(1.87)	(1.86)	(-0.46)	(-0.13)	(-0.12)	(-0.13)
Cohabitees	1.179***	1.261***	1.219***	1.217***	-0.290*	-0.257	-0.259	-0.259
	(4.88)	(5.16)	(5.00)	(5.00)	(-2.09)	(-1.84)	(-1.86)	(-1.85)
2nd lowest Quint.	1.254***	1.253***	1.175***	1.174***	-0.457***	-0.452***	-0.442***	-0.443***
	(6.34)	(6.33)	(5.95)	(5.94)	(-3.45)	(-3.42)	(-3.35)	(-3.35)
Mid. Quintile	1.926***	1.897***	1.743***	1.741***	-0.549***	-0.565***	-0.545***	-0.545***
	(9.91)	(9.74)	(8.95)	(8.94)	(-4.51)	(-4.64)	(-4.47)	(-4.47)
2nd highest Quint.	2.402***	2.354***	2.149***	2.145***	-0.778***	-0.803***	-0.772***	-0.770***
	(12.23)	(11.91)	(10.84)	(10.81)	(-6.33)	(-6.51)	(-6.24)	(-6.22)
Highest Quint.	2.857***	2.782***	2.535***	2.530***	-0.692***	-0.728***	-0.683***	-0.683***
	(14.12)	(13.58)	(12.31)	(12.28)	(-5.52)	(-5.76)	(-5.36)	(-5.36)
Lim. illness	-5.927***	-5.947***	-5.852***	-5.852***	2.095***	2.084***	2.062***	2.061***
	(-39.98)	(-40.05)	(-39.43)	(-39.43)	(22.14)	(21.99)	(21.69)	(21.68)
Non-lim. illness	-0.902***	-0.910***	-0.912***	-0.913***	0.283**	0.278**	0.280**	0.280**
	(-5.96)	(-6.01)	(-6.04)	(-6.04)	(2.95)	(2.91)	(2.93)	(2.93)
Male	-0.480***	-0.495***	-0.421***	-0.420***	-0.214**	-0.222**	-0.235**	-0.235**
	(-4.16)	(-4.28)	(-3.63)	(-3.63)	(-2.95)	(-3.05)	(-3.23)	(-3.22)
Med. Educ. Qual.	-1.284***	-1.296***	-1.168***	-1.168***	0.0220	0.0132	-0.00531	-0.00472
	(-9.78)	(-9.87)	(-8.87)	(-8.87)	(0.27)	(0.16)	(-0.06)	(-0.06)
Low Educ. Qual.	-1.871***	-1.889***	-1.669***	-1.665***	0.299**	0.289*	0.250*	0.248*
	(-10.39)	(-10.48)	(-9.21)	(-9.18)	(2.58)	(2.50)	(2.15)	(2.13)
Children		-0.343*	-0.382**	-0.383**		-0.187*	-0.180*	-0.179
		(-2.30)	(-2.58)	(-2.58)		(-2.04)	(-1.96)	(-1.95)
Smoker			-1.571***	-1.569***			0.285**	0.285**
			(-10.04)	(-10.02)			(2.92)	(2.91)
Urban				-0.0698				0.0365
				(-0.54)				(0.50)
Constant	47.76***	47.97***	48.97***	49.03***	3.403***	3.472***	3.254***	3.243***
	(41.64)	(41.70)	(42.50)	(42.37)	(4.71)	(4.80)	(4.48)	(4.46)
Observations	21292	21292	21292	21292	4767	4767	4767	4767

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

*Notes:*Data are obtained from the Health Survey For England (2011-2014). The regressor for regression (1)-(4) is the WEMWB scale (greater values are better) and for (5)-(8) The GHQ scale (smaller values are better). Year dummies are included throughout.

Chapter 3

Health and Optimal Taxation

3.1 Introduction

Since the seminal papers of Judd (1985) and Chamley (1986) the literature on optimal taxation has focused on whether it is optimal to tax capital income in the absence of non-distortionary taxation. Early studies[1] verified the results of the optimality of zero capital income taxation in the long run using a representative agent framework. As Lucas (1990) notes:

> "When I left graduate school, in 1963, I believed that the single most desirable change in the U.S. tax structure would be the taxation of capital gains as ordinary income. I now believe that neither capital gains nor any of the income from capital should be taxed at all. My earlier view was based on what I viewed as the best available economic analysis, but of course I think my current view is based on better analysis."

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[1] See for example Jones, Manuelli and Rossi (1997) and Atkeson, Chari and Kehoe (1999)

However subsequent studies identified three main specification under which the optimal capital tax rate is different from zero. The first branch of the literature focuses on liquidity constraints and uninsured idiosyncratic risk (Hubbard and Judd, 1986; Aiyagari, 1994) where the agents do not save optimally and capital taxation acts as an instrument to influence savings decisions. The second branch of the literature focuses on the wedge between age-specific optimal labour income tax rates, since labour supply and consumption are generally not constant over the life-cycle. If the government is constrained in using a uniform labour income tax rate, a positive capital income tax can be implemented in order to achieve the second best allocation (Erosa and Gervais, 2002; Garriga, 2003). Finally, Conesa, Kitao and Krueger (2009) incorporating both the above motivations of a non-zero capital income tax, they quantitatively assess the magnitude of the capital income tax rate when the social welfare function takes into account the *distribution* of wealth which is affected by innate ability and productivity shocks.

With government spending accounting for a significant share of GDP, the optimal tax policy can have a significant effect on growth and welfare. Capital income, labour income and consumption tax rates vary significantly between countries and there are substantial changes over time (Trabandt and Uhlig, 2011), which raises the question of whether tax rates are set optimally. Furthermore, health care spending and the ageing of the population applies additional pressure on government finances, which puts health care and pension financing on the center stage of the public debate.

This paper contributes to the literature by incorporating health care spending in a life cycle model and studies the effects of health on optimal taxation in a quantitative overlapping generations model. In our model, health is a stock that depreciates over time and it can be replenished by medical spending, affecting the quality of life of the households, the probability of survival and labour productivity. We abstract from liquidity constraints, idiosyncratic risk and the wealth distribution, hence our analysis is restricted on the second branch of the literature, studying elasticity differentials between cohorts.

First, we solve for the decentralized equilibrium for the UK economy, in order to calibrate the model and assess whether our model can match key moments of interest using the current tax policy. Next, using the same specification, we obtain the second best allocation and the optimal tax policy, taking into account the distortions of capital income, labour income and health care spending taxation on savings, labour supply and the level of health respectively. Finally, we investigate the effects of technological progress in the medical sector that affects longevity on the optimal path of the tax policy, taking into account the ageing of the population. Hence, we can assess what is the optimal financing of increased government spending on health care and social security caused by the ageing of the population, endogeneizing the effects of increased life expectancy on labour supply, saving and health care spending decisions of the households and the subsequent optimal tax policy.

Our results suggest that optimal capital and labour income tax rates are affected by health via three channels; First, by endogeneizing longevity the optimal capital income tax rate is non-zero even if the government can use age-dependent labour income tax rates, in contrast to the results in the literature (Erosa and Gervais, 2002; Garriga, 2003; Peterman, 2015). Secondly, varying labour productivity due to health deterioration over the life-cycle, results in age-dependent optimal labour income tax rates. If the government cannot condition labour income taxes on age, then the government can use capital income taxes to achieve the same effect, which can amplify or diminish the effect of endogenous longevity on capital income tax rates described above. Our simulations suggest that the cumulative effect of endogenous longevity and labour productivity is an optimal capital income tax rate of approximately 7.7%. Lastly, productivity growth in the medical sector which directly or indirectly affects longevity creates an evolutionary path of optimal capital income tax rate. Cohorts' decisions regarding medical spending are not affected homogeneously, affecting over time the wedge of health care spending elasticities the capital income tax compensates for. Furthermore, higher life expectancy affects the savings decision of the households, since they discount the future less, reducing the distortion of capital income tax. Our simulations suggest that an increase in social security payments due to increased longevity is optimal to be financed through an increase of the capital income tax rate, in contrast to a fiscally equivalent increase in pension payments due to an increase in the pension replacement rate, where the government reduces the capital income tax rate. Since there is no evidence suggesting a slow down in improvements in medical technology and longevity (Whitehouse, 2007), it is optimal for the capital income tax to adjust for changes in longevity. This result has significant policy implications since the ageing of the population, changes not only the level of the optimal tax rates (in order to finance a more burdensome PAYG pension system) but also the optimal *relative* tax rates between labour income, health care spending and capital income.

The paper closest to ours is by Peterman (2015) in which he studies the effect of endogenous human capital accumulation over the life-cycle on optimal capital and labour income taxation. In the model, human capital accumulates through learning-by-doing, which reduces the elasticity of labour supply of younger cohorts who face the trade-off between leisure today and labour income earnings in later periods. The effects of health as human capital on optimal taxation follow the results of learning-by-doing, since health is a stock that depreciates over time and instantaneous health care spending affects subsequent periods. However the underlying mechanism is this chapter is different. In our model, health depreciation affects optimal capital income tax rates through the productivity channel (as in Peterman (2015)), but optimal capital income tax rates are also affected by the inability of the government to discriminate between the cohorts with respect to health care spending taxation. Moreover, the characteristics of health affect households beyond labour productivity, affecting per period utility and the number of periods households can derive utility from, aspects that cannot be studied in a model of pure human capital accumulation[2]. The introduction of endogenous longevity has non-trivial effects as described above both for the level of optimal taxation and the relation between labour income, capital income and health care spending tax rates.

The rest of the paper is organized as follows. In the next section we set up the environment under which we are going to study the effects of health on optimal taxation. In section three, we derive analytically the second best allocation and the optimal capital income, labour income and health care spending tax rates. In section four, we describe the functional forms and we calibrate the model using the decentralized equilibrium and we subsequently solve for the second best allocation quantitatively. We conclude with section five.

3.2 The Model

The model is a standard general equilibrium overlapping generations model with J cohorts. Households make decisions with respect to consumption, labour supply and health care spending, with the latter affecting the probability of survival between cohorts, labour productivity and the level of utility. There is a representative firm which produces a single composite good Y_t utilizing capital and labour. Finally, the government runs a balanced budget every period, taxing capital income, labour income, consumption[3] and health care spending and provides a Pay-As-You-Go social security

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[2] Leroux, Pestieau and Ponthiere (2009) introduce endogenous longevity, where the government subsidises savings. However, their results are driven by myopic households who do not perfectly optimize over their life-cycle, accumulating suboptimal savings. This is not the main source of non-zero capital taxation in our model since agents are rational and they have perfect foresight.

[3] Consumption taxation as an instrument is redundant from the perspective of second best optimal government policy since the government can influence consumption through the capital income tax. However, consumption taxation accounts for a significant fraction of government revenues and we incorporate a flat, exogenous consumption tax in order to be closer to

schemes for cohorts $j > J_R$.

3.2.1 Households

Households survive up to J periods and derive utility from consumption and the level of health and disutility from labour. Their life-time utility, which takes into account the probability of survival is denoted as:

$$U = \sum_{j=1}^{J} \beta^{j-1} P_{j,t}\left(h_{j,t}\left(m_{j,t}\right)\right) u_{j,t}\left(c_{j,t}, h_{j,t}\left(m_{j,t}\right), l_{j,t}\right) \tag{3.1}$$

with:

$$P_{j,t}\left(h_{j,t}\left(m_{j,t}\right)\right) = \prod_{i=1}^{j-1} [p\left(h_{i,t}\left(m_{i,t}\right)\right)] p\left(h_{j,t}\left(m_{j,t}\right)\right) \tag{3.2}$$

where j denotes age cohort, $c_{j,t}$, $h_{j,t}\left(m_{j,t}\right)$ and $m_{j,t}$ are consumption, level of health and aggregate medical spending in period t for cohort j respectively, β is the discount rate, while $p_{j,t}\left(h_{j,t}\left(m_{j,t}\right)\right)$ denotes the probability of surviving to age cohort j, conditional on surviving until $j-1$ and $P_{j,t}\left(h_{j,t}\left(m_{j,t}\right)\right)$ the unconditional probability of being alive at cohort j.

In addition, as in Feng (2010) we assume the following function for the probability of survival:

$$p_j\left(h_{j,t}\right) = 1 - e^{-\left(a_{p,j} h_{j,t}\right)^{b_{p,j}}} \tag{3.3}$$

where a_{p_j} and b_{p_j} are scale and curvature parameters respectively, calibrated to fit the age specific probability of survival given a level of health. The latter is described as in

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the actual government policy.

Zhao (2014):

$$h_{j,t} = h_{j-1,t-1}\left(1-\delta_j\right) + Q_j m_{j,t}^{z_j} \tag{3.4}$$

with δ_j being the health depreciation parameter and Q_j, z_j are the scale and curvature parameters for the health production function.

In our model, (3.4) and (3.3) endogeneize the level of health and the probability of survival, taking into account the natural deterioration of health over time (δ_j), the decreasing returns of medical spending on the level of health (since $z_j < 1$) and the indirect effect of medical spending on the probability of survival through the level of health. These assumptions are crucial for the realistic representation of the level of health and medical spending and reflect the burden of health care spending of an ageing population.

The households face the following budget constraint:

$$\begin{aligned}&\left(1-\tau_j^w\right)\left(l_{j,t} w_t e^{\phi h_{j,t}} + SS_t\right) + \left(1 + r\left(1-\tau_j^a\right)\right) a_{j-1,t-1} = \\ &= \left(1+\tau^c\right) c_{j,t} + \left(1+\tau_j^h\right) m_{j,t} + a_{j,t}\end{aligned} \tag{3.5}$$

where τ_j^w, τ_j^h and τ_j^a denote the cohort specific labour income and health care spending and capital income tax rates respectively, τ^c is the consumption tax, w_t is the wage rate, r_t the interest rate and $a_{j,t}$ denotes savings. In addition households receive pensions SS_t such that $SS_t = \chi w_t e^{\phi h_j}$ for $j \geq J_R$ and zero otherwise[4], with J_R being the age of eligibility for pension payments, $w_t e^{\phi h_j}$ is the effective wage and χ is the replacement rate.

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[4] For the effects of taxable or non taxable pensions see Conesa and Garriga (2009). In a nutshell, taxable pensions affect the optimal level of labour income tax, since pension receipts are completely inelastic affecting the age-specific optimal labour income tax. We choose this formulation since it is closer to the actual government policy in most developed countries.

3.2.2 Firms

There is one representative firm, hiring labour and capital producing a single composite good according to the production function:

$$Y_t = AK_{t-1}^{\alpha}\hat{L}_t^{1-\alpha} \quad \forall t, \tag{3.6}$$

where

$$K_t = \sum_{j=1}^{J-1} \mu_{j,t}k_{j,t} \quad \forall t, \tag{3.7}$$

$$\hat{L}_t = \sum_{j=1}^{j_R} \mu_{j,t}l_{j,t}e^{\varphi h_{j,t}} \quad \forall t, \tag{3.8}$$

with $\mu_{j,t} = \frac{p(h_{j-1,t-1})}{1+n}\mu_{j-1,t-1}$ denoting the cohort size. In our model, the population of young agents grows at a constant rate n and they bear children at the end of the first period of life, before the mortality rate is realized.

Assuming perfect competition, the wage and interest rates are equal to their marginal products:

$$w_t = (1-a)\frac{Y_t}{\hat{L}_t} \quad \forall t, \tag{3.9}$$

$$r_t = a\frac{Y_t}{K_{t-1}} - \delta \quad \forall t, \tag{3.10}$$

3.2.3 The Government

The government runs a balanced budget every period[5], collecting taxes from or subsidizing consumption, labour income, health care expenditure and capital income in order to finance an exogenous sequence of government spending G_t and pension payments as in:

$$\tau^{\mathrm{c}} \sum_{j=1}^{J} \mu_{j,t} c_{j,t} + \sum_{j=1}^{J} \mu_{j,t} \tau_{\mathrm{j}}^{\mathrm{h}} m_{j,t} + \sum_{j=1}^{J} \mu_{j,t} \tau_{\mathrm{j}}^{w} l_{j,t} w_t e^{\phi h_{j,t}} + \sum_{j=1}^{J} \mu_{j,t} \tau_{\mathrm{j}}^{\alpha} r_t a_{j,t} + B_{j,t} = G + \sum_{j=J_R}^{J} \mu_{j,t} SS_t \quad \forall t \tag{3.11}$$

with $B_{j,t} = \sum_{j=1}^{J} \mu_{j,t} \left(1 - P_{j-1,t}\right) a_{j,t}$ denoting accidental bequests left by deceased households that are seized by the government[6].

Finally, the resource constraint of the economy is expressed as:

$$C_t + K_t + M_t + G_t - Y_t \left(K_{t-1}, L_t\right) - \left(1 - \delta\right) K_{t-1} = 0 \quad \forall t, \tag{3.12}$$

where $C_t = \sum_{j=1}^{J} \mu_{j,t} c_{j,t}$, $M_t = \sum_{j=1}^{J} \mu_{j,t} m_{j,t}$ and $G_t = gY_t$ denotes the exogenous sequence of unproductive government spending and δ is the depreciation rate.

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[5] We abstract from government debt because it is beyond the scope of this paper. For a comprehensive examination of debt in the Ramsey problem see Erosa and Gervais (2002) and Conesa, Kitao and Krueger (2009). Under certain conditions the government can accumulate negative debt in order to finance future government spending via interest rate payments or accumulate large positive debt, depending on the relative weight on future generations.

[6] The assumptions regarding bequest motives and the manner bequests are taxed have significant effects on the optimal capital income taxation (Fuster, Imrohoroglu and Imrohoroglu, 2008; Peterman, 2013). If bequests are intentional, the optimal capital income is lower than the optimal capital income for unintended bequest since the latter are completely inelastic. In addition, with accidental bequest, distinguishing between ordinary capital income and bequests (for example introducing an inheritance tax), results in confiscatory tax rates since there is no distortion to the optimal decision of the households. For simplicity, we adopt the latter specification, assuming that bequest are accidental and the government imposes a non-distortionary inheritance tax of 100%.

3.3 Competitive Equilibrium and Second Best

Here we present the formal definitions and the analytical derivations of the competitive equilibrium and the second best optimal fiscal policy of the government. We focus on the decentralized equilibrium for two reasons; first, it is necessary to obtain the optimal decision rules of the household in order to solve for the second best allocation, where the government takes into account not only the budget constraints of the agents but also the first order conditions. Secondly, in the quantitative exercise, the decentralized equilibrium serves as a benchmark case in order to compare the second best allocation. Furthermore, we focus on the second best allocation since it represents a more realistic description of the actual government policy.

3.3.1 Competitive Equilibrium

In the competitive equilibrium, households take the fiscal policy of the government as given and they maximize their life-time utility subject to the budget constraint. In order for this model economy to clear, we set exogenously the fiscal variables, but the labour income tax is set endogenously in order to balance the government budget. The formal definition is described below:

Definition 2. (Competitive Equilibrium): *Given fiscal policy* π: $\{\tau_t^a\}_{t=0}^{\infty}$, $\{\tau_t^w\}_{t=0}^{\infty}$, $\{\tau_t^c\}_{t=0}^{\infty}$, $\{\tau_t^h\}_{t=0}^{\infty}$, $\{\chi_t\}_{t=0}^{\infty}$, $\{g_t\}_{t=0}^{\infty}$ *a competitive equilibrium for this economy is the sequence of individual allocations* $\left\{\{c_{j,t}, l_{j,t}, m_{j,t}, a_{j,t}\}_{j=1}^{J}\right\}_{t=0}^{\infty}$, *production factors* $\{K_t, L_t\}_{t=0}^{\infty}$ *and relative prices* $\{r_t, w_t\}_{t=0}^{\infty}$, *such that:*

1. *Households maximize life-time utility (3.1) subject to their budget constraint (3.5)*

2. *Labour and capital are compensated as in (3.9) and (3.10) respectively for all t*
3. *The government budget constraint (3.11) is satisfied for all t*
4. *The resource constraint (3.12) holds for all t*

The first order necessary conditions for optimality with respect to consumption, medical spending, labour supply and savings respectively are:

$$[c_{j,t}] \qquad \tilde{\beta}_{j,t} u_{c_{j,t}} = \lambda_t \left(1+\tau_t^c\right) \qquad \forall t, j \tag{3.1}$$

$$[m_{j,t}] \qquad \tilde{\beta}_{j,t} \tilde{u}_{m_{j,t}} = \lambda_t \left(1+\tau_t^h\right) - \Phi_{j,t} \qquad \forall t, j \tag{3.2}$$

$$[l_{j,t}] \qquad \tilde{\beta}_{j,t} u_{l_{j,t}} = \lambda_t \left(1+\tau_t^w\right) w_t e^{\phi h_{j,t}} \qquad \forall t, j \tag{3.3}$$

$$[a_{j,t}] \qquad \lambda_t = \lambda_{t+1} \left[1 + \left(1-\tau_t^a\right) r_t\right] \qquad \forall t, j \tag{3.4}$$

where:

$$\tilde{\beta}_{j,t} = \beta^{j-1} P_{j,t}\left(h_{j,t}\left(m_{j,t}\right)\right) \quad , \tag{3.5}$$

$$\tilde{u}_{m_{j,t}} = u_{j,m_{j,t}} + \sum_{i=j+1}^{J} P_{i,m_{j,t}} u_i + \sum_{i=j+1}^{J} P_i u_{i,m_{j,t}} \quad , \tag{3.6}$$

$$\Phi_{j,t} \equiv \sum_{i=j+1}^{J} \lambda_{t+i-j} \left(1-\tau_{i,t+i-j}^{w}\right) \phi h_{i,m_{j,t}} w_{t+i-j} e^{\phi h_{j,t+i-j}} \tag{3.7}$$

Which becomes after substituting (3.3) into (3.7):

$$\Phi_{j,t} = -\sum_{i=j+1}^{J} \tilde{\beta}_{i,t+i-j} u_{l_{i,t+i-j}} \phi h_{i,m_{j,t}} \tag{3.8}$$

In our model, $\tilde{\beta}_{j,t}$ expresses the effective discount rate after taking into account the probability of survival and $\tilde{u}_{m_{j,t}}$, $\Phi_{j,t}$ are the effects of the endogenous probability of survival and labour productivity on the optimal decision of the household. Since health is a stock that depreciates over time and households can invest in their level of health through health care spending $m_{j,t}$, medical decisions in period j affect the probability of survival, the level of utility and labour productivity of all subsequent periods, which is taken into account in the optimal decision of the households. – The optimal decisions of the households with respect to consumption, health care spending, labour supply and savings described above, are crucial not only for the decentralized equilibrium, which is used as a benchmark, but the second best allocation as well. Households choose the sequence of their decisions taking into account the effective discount $\tilde{\beta}$ rate, which is endogenously determined in our model. Hence, changes in longevity have a direct effect on the effective discount rate and the spending and saving decision of the households. Furthermore, households choose the optimal level of health care spending considering the effects of health on longevity (3.6) and effective labour supply (3.8), while the labour supply decision per se is affected by the age-specific productivity of the households (3.3).

The second best allocation derived in the next section, takes into account these optimality conditions of the households and shapes the optimal government policy.

3.3.2 The Second Best

The government's problem is to maximize the lifetime utility of all cohorts subject to the agent's first order conditions, the agent's budget constraints and the resource constraint of the economy[7]. We rely on the primal approach to obtain the optimal set of tax instruments, where the government maximizes welfare subject to the implementability constraint, which takes into account the agent's budget constraint and first

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[7] The government budget is balanced due to Walras' Law

order conditions to substitute for prices and the resource constraint of the economy (Atkinson and Stiglitz, 1976; Lucas and Stokey, 1983). This ensures that the efficient allocation chosen by the government can be decentralized satisfying the agent's budget constraint and the agent's first order condition.

In the analytical models below, we choose to study the effects of productivity and probability of survival separately for the sake of clarity. The two analytical models that are presented in the following section can distinguish the two channels via which health affects the optimal taxation chosen by the government.

Endogenous Labour Productivity

First, we focus on the effects of endogenous labour supply treating the probability of survival as exogenous from the perspective of the household. We denote the exogenous probability of survival as $\bar{P}_j$. Hence, we substitute (3.6) and (3.5) from the household's maximization problem with the following expressions[8]:

$$U_{m_{j,t}} = u_{m_{j,t}} \quad \forall t, j, \tag{3.9}$$

$$\tilde{\beta}_{j,t} = \beta^{j-1} \bar{P}_{j,t} \quad \forall t, j \tag{3.10}$$

The government's problem can be expressed as:

$$\max_{\left\{\left\{c_{j,t}, m_{j,t}, l_{j,t}\right\}_{j=1}^{J}, K_t\right\}_{t=0}^{\infty}} \sum_{t=0}^{\infty} \sum_{j=1}^{J} \theta^t \left[\mu_{j,t} \beta^{j-1} U\left(c_{j,t}, h_{j,t}\left(m_{j,t}\right), l_{j,t}\right)\right] \tag{3.11}$$

where θ is the relative weight of each generation, subject to the budget constraint of

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[8] With exogenous probability of survival, the marginal utility with respect to medical spending, affects only the level of instanteneous utility and the effective discount rate is exogenous.

the households (3.5), the households' first order conditions (3.1)-(3.4) and the resource constraint of the economy (3.12) for all t.

Proposition 1 (**Implementable Allocations**)**.** The second best allocation $\left\{ \{c_{j,t}, l_{j,t}, m_{j,t}, a_{j,t}\}_{j=1}^{J} \right\}_{t=0}^{\infty}$ that maximizes the government's objective function (3.11) subject to the implementability constraint:

$$\sum_{j=1}^{J} \beta^{j-1} P_j \left[\begin{array}{l} u_{c_{j,t+j-1}} c_{j,t+j-1} + \left(u_{m_{j,t+j-1}} - u_{l_{j,t+j-1}} \phi h_{j,m_j} l_{j,t+j-1} \right) m_{j,t+j-1} \\ + u_{l_{j,t+j-1}} \left(l_{j,t+j-1} + \frac{SS_{t+j-1}}{w e^{\phi h_{j,t+j-1}}} \right) \end{array} \right] = 0 \quad (3.12)$$

and the resource constraint of the economy (3.12) can be decentralized given tax policy $\pi = \left\{ \tau^{\alpha}, \tau^{h}, \tau^{c}, \tau^{w} \right\}_{t=0}^{\infty}$ such that:

$$\tau_{j,t}^{h} = \frac{(1+\tau_t^c)\left(\tilde{\beta}_{j,t} \tilde{u}_{m_{j,t}} + \Phi_{j,t} \right)}{\tilde{\beta}_{j,t} u_{c_{j,t}}} - 1 \quad \forall t, j \quad (3.13)$$

$$\tau_{j,t}^{w} = \frac{u_{l_{j,t}} (1+\tau_t^c)}{w_t e^{\phi h_{j,t}} u_{c_{j,t}}} + 1 \quad \forall t, j \quad (3.14)$$

$$\tau_{j,t}^{a} = \frac{1}{r_t} \left[(1+r) - \frac{\tilde{\beta}_{j,t} u_{c_{j,t}}}{\tilde{\beta}_{j+1,t+1} u_{c_{j+1,t+1}}} \right] \quad \forall t, j \quad (3.15)$$

with $\tau^c = \bar{\tau}^c$

Proof. First we need to derive the implementability constraint, which is the household's budget constraint where we have substituted the tax rates with the first order conditions of the household. Hence, the implementability constraint encompasses both restrictions of the government's maximization problem[9]. Multiplying the first

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[9] Another merit of the primal approach is that substituting the tax rates with the first order conditions of the agents and using the resource constraint of the economy rather than the government budget constraint, the government doesn't need to maximize over the tax policy π explicitly. Instead, we can construct the optimal tax rates ex-post, substituting the second

order conditions of the household (3.1)-(3.4) with their respective variable we obtain:

$$\tilde{\beta}_{j,t} u_{c_{j,t}} c_{j,t} = \lambda_t \left(1 + \tau_t^c\right) c_{j,t} \quad \forall t, j \tag{3.16}$$

$$\left(\tilde{\beta}_{j,t} \tilde{u}_{m_{j,t}} + \Phi_{j,t}\right) m_{j,t} = \lambda_t \left(1 + \tau_t^h\right) m_{j,t} \quad \forall t, j \tag{3.17}$$

$$\tilde{\beta}_{j,t} u_{l_{j,t}} l_{j,t} = -\lambda_t \left(1 - \tau_t^w\right) w_t e^{\phi h_{j,t}} l_{j,t} \quad \forall t, j \tag{3.18}$$

$$\lambda_t a_{j,t} = \lambda_{t+1} \left[1 + \left(1 - \tau_t^a\right) r_t\right] a_{j,t} \quad \forall t, j \tag{3.19}$$

Adding up (3.16)-(3.19) for all j, we obtain:

$$\begin{aligned}
&\sum_{j=1}^{J} \tilde{\beta}_{j,t} \left(u_{c_{j,t}} c_{j,t} + \left(\tilde{\beta}_{j,t} \tilde{u}_{m_{j,t}} + \Phi_{j,t}\right) m_{j,t} + \tilde{\beta}_{j,t} u_{l_{j,t}} l_{j,t}\right) = \\
&= \sum_{j=1}^{J} \lambda_t \left[\left(1 + \tau_t^c\right) c_{j,t} + \left(1 + \tau_{j,t}^h\right) m_{j,t} - \left(1 - \tau_{j,t}^w\right) w_t e^{\phi h_{j,t}} l_{j,t}\right] = \\
&= \sum_{j=1}^{J} \lambda \left(1 - \tau_{j,t}^w\right) SS_t
\end{aligned} \tag{3.20}$$

From equation (3.20), we observe that we can rewrite the household's budget constraint (3.5) with the first order conditions instead of tax rates. However, the right hand side of the (3.16)-(3.19) does not include the pension receipts since it is not a household decision. Hence, from the budget constraint of the household:

$$\sum_{j=1}^{J} \lambda_t \left[\left(1 + \tau_t^c\right) c_{j,t} + \left(1 + \tau_{j,t}^h\right) m_{j,t} - \left(1 - \tau_{j,t}^w\right) w_t e^{\phi h_{j,t}} l_{j,t}\right] = \sum_{j=1}^{J} \lambda \left(1 - \tau_{j,t}^w\right) SS_t$$

From equation (3.3) of the household's first order conditions, if we re-arrange with respect to the labour income tax :

$$\sum_{j=1}^{J} \lambda \left(1 - \tau_{j,t}^w\right) SS_t = -\sum_{j=1}^{J} \tilde{\beta}_{j,t} \frac{u_{l_{j,t}}}{w_t e^{\phi h_{j,t}}} SS_t \tag{3.21}$$

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best allocation into the first order conditions of the agents, as described below.

Substituting (3.21) into (3.20) and re-arranging we obtain:

$$\sum_{j=1}^{J} \beta^{j-1} P_j \left[\begin{array}{l} U_{c_{j,t+j-1}} c_{j,t+j-1} + \left(U_{m_{j,t+j-1}} - U_{l_{j,t+j-1}} \phi h_{j,m_j} l_{j,t+j-1} \right) m_{j,t+j-1} + \\ + U_{l_{j,t+j-1}} \left(l_{j,t+j-1} + \frac{SS_{t+j-1}}{w e^{\phi h_{j,t+j-1}}} \right) \end{array} \right] = 0$$

Hence, the allocation obtained from solving the government's maximization described above is the second best allocation and satisfies the first order conditions and the budget constraint of the household (via the implementability constraint), the resource constraint of the economy and the government budget constraint.

This allocation can be decentralized if and only if the government sets the tax rate policy π such that it satisfies the restrictions described above. Thus, we can obtain the optimal tax rates by re-arranging the first order conditions of the household with respect to the tax rates and substitute the second best allocation $\left\{ \left\{ c_{j,t}, l_{j,t}, m_{j,t}, a_{j,t} \right\}_{j=1}^{J} \right\}_{t=0}^{\infty}$ and the exogenous consumption tax τ^c. It is trivial to show that by re-arranging equations (3.16)-(3.19) we can obtain (3.13)-(3.15).

■

The second best allocation described above is the unrestricted government problem, since the government can choose an allocation such that tax rates are not uniform across cohorts. However, in practice governments cannot condition tax rates on age, at least not perfectly, hence additional restrictions need to be implemented. In the quantitative model in section four, we solve for both the restricted and the unrestricted case, since there are sizable effects on tax rates.

Proposition 2. If the government is restricted in using uniform tax rates across cohorts, hence cannot use age-dependent taxation, the following additional restrictions need to be implemented in the government's maximization problem:

$$\frac{U_{c_{1,t}}}{U_{c_{2,t+1}}} = ... = \frac{U_{c_{J-1,t}}}{U_{c_{J,t+1}}} \quad \forall t, \tag{3.22}$$

$$\frac{U_{c_{1,t}}}{U_{l_{1,t}}} e^{\phi h_{1,t}} = ... = \frac{U_{c_{J,t}}}{U_{l_{J,t}}} e^{\phi h_{J,t}} \quad \forall t, j, \tag{3.23}$$

$$\frac{\tilde{\beta}_{1,t}\tilde{u}_{m_{1,t}} - \Phi_{1,t}}{\tilde{\beta}_{1,t}u_{c_{1,t}}} = ... = \frac{\tilde{\beta}_{J,t}\tilde{u}_{m_{J,t}} - \Phi_{J,t}}{\tilde{\beta}_{J,t}u_{c_{J,t}}} \quad \forall t, j \tag{3.24}$$

Proof. It is straightforward to show that for the tax rates to be uniform across cohorts the following condition with respect to health care spending, labour and capital tax must hold for any j and $j+1$, using the expression of the optimal tax rates (3.13)-(3.15):

$$\frac{(1+\tau_t^c)\left(\tilde{\beta}_{j,t}\tilde{u}_{m_{j,t}} + \Phi_{j,t}\right)}{\tilde{\beta}_{j,t}u_{c_{j,t}}} - 1 = \frac{(1+\tau_t^c)\left(\tilde{\beta}_{j+1,t}\tilde{u}_{m_{j+1,t}} + \Phi_{j+1,t}\right)}{\tilde{\beta}_{j+1,t}u_{c_{j+1,t}}} - 1 \tag{3.25}$$

$$\frac{u_{l_{j,t}}(1+\tau_t^c)}{w_t e^{\phi h_{j,t}} u_{c_{j,t}}} + 1 = \frac{u_{l_{j+1,t}}(1+\tau_t^c)}{w_t e^{\phi h_{j+1,t}} u_{c_{j+1,t}}} + 1 \tag{3.26}$$

$$\frac{1}{r_t}\left[(1+r_t) - \frac{\tilde{\beta}_{j,t}u_{c_{j,t}}}{\tilde{\beta}_{j+1,t+1}u_{c_{j+1,t+1}}}\right] = \frac{1}{r_{t+1}}\left[(1+r_{t+1}) - \frac{\tilde{\beta}_{j+1,t+1}u_{c_{j+1,t+1}}}{\tilde{\beta}_{j+2,t+2}u_{c_{j+2,t+2}}}\right] \tag{3.27}$$

Simplifying the expressions, we obtain the additional restrictions (3.22)-(3.24).

■

Even in the model with exogenous probability of survival, health has significant effects on the Ramsey problem of optimal taxation. Introducing health as a form of human capital that naturally deteriorates over time, changes the elasticity of health care spending over the life cycle, since both the level of health and the effectiveness of health care spending diminishes with age[10]. The conditions described in Garriga (2003) and Peterman (2013) for zero capital income taxation in life-cycle models seize to hold. Even if there are no incentives to use age dependent labour income taxation, the peculiarity of health dictates different tax rates across cohorts. In the restricted version of the model, the optimal capital income tax is not zero, even if there is only one cohort supplying labor[11], or the Frisch elasticity of labour supply is contstant over the life cycle.

Proposition 3. In the model with endogenous productivity, even if there are two cohorts with only the first supplying labour or the Frisch elasticity is constant over the life-cycle the government has still an incentive to use age-dependent tax rates resulting in a non-zero capital income tax rate when the government is restricted to use uniform tax rates.

Proof. We need to show that in the unrestricted version of the model, the optimal capital income tax is indeed zero and the optimal level of health care spending tax is not constant over the life cycle. In the restricted version of the model, the latter results in non-zero capital income tax.

As in Garriga (2003), let $V\left(c_{j,t}, h_{j,t}\left(m_{j,t}\right), l_{j,t}, \rho_{t-j}\right)$ be the pseudo-utility function denoted as:

$$V\left(c_{j,t}, h_{j,t}\left(m_{j,t}\right), l_{j,t}, \rho_{t-j}\right) = U\left(c_{j,t}, h_{j,t}\left(m_{j,t}\right), l_{j,t}\right) + \rho_{t-j}\Omega_{j,t} \tag{3.28}$$

where $\Omega_{j,t}$ is the implementability constraint and ρ_{t-j} is the Lagrange multiplier of the implementability constraint.

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[10] Even if we exclude age-specific parameters in the health production function (3.4), health deteriorates faster as the household ages, resulting in lower effectiveness of instantaneous health care spending for future periods.

[11] If the economy consists of only two cohorts, with the first one supplying labour, there is a single labour income tax rate and no incentive to use age-dependent labour income taxation or a non-zero capital income tax in the restricted model

The government's problem for the second best allocation is to maximize the lifetime utility of a newborn household[12]:

$$\sum_{j=1}^{J} \tilde{\beta}_{t+j-1,j} V\left(c_{t+j-1,j}, h_{t+j-1,j}\left(m_{,t+j-1j}\right), l_{t+j-1,j}, \rho_{t+j-1,j}\right) \tag{3.29}$$

subject to the resource constraint of the economy (3.12). From the Lagrangian, the first order necessary condition with respect to consumption, health care spending, labour supply and savings are the following:

$$[c_{j,t}] \qquad \tilde{\beta}_{j,t+j-1} V_{c_{j,t+j-1}} + \theta^{t+j-1} \xi_{t+j-1} = 0 \qquad \forall t, j \tag{3.30}$$

$$[m_{j,t}] \qquad \tilde{\beta}_{j,t+j-1} V_{m_{j,t+j-1}} + \theta^{t+j-1} \xi_{t+j-1} Y_{m_{j,t+j-1}} = 0 \qquad \forall t, j \tag{3.31}$$

$$[l_{j,t}] \qquad \tilde{\beta}_{j,t+j-1} V_{l_{j,t+j-1}} - \theta^{t+j-1} \xi_{t+j-1} Y_{l_{j,t+j-1}} = 0 \qquad \forall t, j \tag{3.32}$$

$$[a_{j,t}] \qquad \theta^{t+j-1} \xi_{t+j-1} - \theta^{t+j} \xi_{t+j} \left(1 + r_t\right) = 0 \qquad \forall t, j \tag{3.33}$$

where ξ is the Lagrange multiplier of the resource constraint.

Forwarding (3.30) one period and substituting in (3.33) we obtain:

$$\frac{\tilde{\beta}_{j,t+j-1} V_{c_{j,t+j-1}}}{\tilde{\beta}_{j+1,t+j} V_{c_{j+1,t+j}}} = \left(1 + r_t\right) \tag{3.34}$$

Substituting (3.34) into the optimal capital income tax (3.15):

$$\tau^{a}_{j,t+j-1} = \frac{\tilde{\beta}_{j,t+j-1}}{\tilde{\beta}_{j+1,t+j} r_t} \left[\frac{V_{c_{j,t+j-1}}}{V_{c_{j+1,t+j}}} - \frac{u_{c_{j,t+j-1}}}{u_{c_{j+1,t+j}}} \right] \tag{3.35}$$

As Garriga (2003) shows, with the standard class of utility functions equation (3.35)

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[12] As in Diamond (1965), Conesa, Kitao and Krueger (2009) and Peterman (2013), we choose for simplicity to solve for a single newborn household since the cohort size does not affect our main results when the probability of survival is exogenous.

is zero since the government has no incentive to distort consumption choices in the unrestricted version of the government's problem[13]

The next step is to show that health care spending tax rates are not uniform across cohorts, since when the government cannot use age-dependent taxation, the Garriga (2003) and Peterman (2013) results with respect to labour income tax become irrelevant and the optimal capital income tax is not zero.

From the optimal health care spending tax (3.13), the ratio of the optimal tax rate of cohort j and $j+1$ becomes:

$$\frac{\tau^h_{j,t}}{\tau^h_{j+1,t}} = \frac{\frac{\left(\tilde{\beta}_{j,t}\tilde{u}_{m_{j,t}}+\Phi_{j,t}\right)}{\tilde{\beta}_{j,t}u_{c_{j,t}}}-1}{\frac{\left(\tilde{\beta}_{j+1,t}\tilde{u}_{m_{j+1,t}}+\Phi_{j+1,t}\right)}{\tilde{\beta}_{j+1,t}u_{c_{j+1,t}}}-1} \tag{3.36}$$

The above ratio cannot be one for two reasons; First, in overlapping generations models the sequence of household's optimal decisions is not constant over the life-cycle, thus m_j and m_{j+1} are not equal. Secondly, recall from equation (3.8) defining the parameter $\Phi_{j,t}$ that even when the probability of survival is exogenous, the nature of health as a stock that depreciates over time influences the optimal medical spending decisions because health affects labour productivity. Health care spending today, affects the level of labour productivity during the current and all subsequent periods. Households, not only face a shorter life-span as they age, but health depreciates faster with age, diminishing the incentive to invest in health as they get older. This diminishing incentive of the household through the life-cycle affects the optimal health care spending tax significantly[14].

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[13] For clarity of exposition, take a two-period overlapping generation model with CRRA utility function and γ the coefficient of relative risk aversion. Then:

[14] In our simulations health care spending tax rates are negative (subsidies) and in the three-generations model the young are subsidized at a rate of 82.4%, the middle-aged at 35.6%, while the old at a rate of 16.5%.

■

The intuition behind this result is that the incorporation of health as an endogenous variable that determines labour productivity affects not only the optimal labour income tax rates faced by each cohort if the Frisch elasticity is not constant during the life-cycle (as in Garriga (2003)), but the optimal tax rates of health care spending as well, which is not eliminated with preferences that assume a constant Frisch elasticity (as in Peterman (2013)). Furthermore, even if there are two cohorts, with the second cohort not supplying labour, households still face different elasticities with respect to health care spending through their life-cycle.

Hence, the results of Garriga (2003) and Peterman (2013) hold as long the government can implement an age-dependent tax system, including health care spending. This is not true for the model with endogenous probability of survival that we study in the next section, where even if the government can discriminate between cohorts, the optimal capital income tax rate is non-zero.

Endogenous Probability of Survival

Now we turn to the effects of endogenous probability of survival on the second best allocation, shutting down the endogenous productivity channel in order to make our results more transparent. We substitute $\Phi_{j,t}$ (the intertemporal labour productivity incentive), the marginal utility of health and the effective discount respectively with the following expressions:

$$\Phi_{j,t} = 0 \quad \forall t, j \tag{3.37}$$

$$U_{m_{j,t}} = \tilde{u}_{m_{j,t}} \quad \forall t, j \tag{3.38}$$

$$\tilde{\beta}_{j,t} = \beta^{j-1} P\left(h_{j,t}\left(m_{j,t}\right)\right) \quad \forall t, j \tag{3.39}$$

The objective of the government is to maximize (3.11) subject to the implementability constraint and the modified resource constraint of the economy (whithout endogenous labour productivity):

$$C_t + K_t + M_t + G_t - Y_t\left(K_{t-1}, L_t\right) - (1-\delta) K_{t-1} = 0 \quad \forall t, \tag{3.40}$$

Naturally, the implementability constraint and the optimal tax policy π are different compared to the previous model, where labour productivity is endogenous and longevity is treated as exogenous. One crucial difference between the previous analytical model and the model with endogenous probability of survival is that the government can no longer maximize the life-time utility of a single representative household since cohort size now matters[15]. In addition, endogenous longevity transforms the household problem from a sequence of allocation over a fixed length of life-cycle to a problem where households also choose the number of periods they can derive utility from, fundamentally changing the optimality conditions (Rossen, 1988). Recall from (3.6), that households make optimal health care spending decisions taking into account the *level* of future utility:

$$\tilde{u}_{m_{j,t}} = u_{j,m_{j,t}} + \sum_{i=j+1}^{J} P_{i,m_{j,t}} u_i + \sum_{i=j+1}^{J} P_i u_{i,m_{j,t}}$$

Both peculiarities of endogenous longevity result in non-zero optimal capital income tax rates even in the unrestricted version of the government problem.

Proposition 4. With endogenous probability of survival, even if the government can

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[15] It is a gross simplification to assume that the social welfare function does not take into account the number of living agents, when the government can directly influence longevity.

make use of age-dependent taxation, the optimal tax rate on capital income is non-zero.

Proof. We follow the same method of obtaining the implementability constraint, multiplying the first order conditions of the household with the respective choice variable and add up the expressions:

$$\sum_{j=1}^{J} \tilde{\beta}_{j,t} \left[u_{c_{j,t}} c_{j,t} + \tilde{u}_{m_{j,t}} m_{j,t} + u_{l_{j,t}} \left(l_{j,t+j-1} + \frac{SS_{t+j-1}}{w e^{\phi h_{j,t+j-1}}} \right) \right] = 0 \quad \forall t, j \tag{3.41}$$

The new optimal tax rates, after re-arranging (3.1)-(3.4) and substituting (3.37)-(3.39) are the following:

$$\tau_t^h = \frac{\tilde{u}_{m_{j,t}} \left(1 + \tau_t^c\right)}{u_{c_{j,t}}} - 1 \quad \forall t, j \tag{3.42}$$

$$\tau_t^w = -\frac{u_{l_{j,t}} \left(1 + \tau_t^c\right)}{w_t e^{\phi h_{j,t}} u_{c_{j,t}}} + 1 \quad \forall t, j \tag{3.43}$$

$$\tau_t^a = \frac{1}{r_t} \left[(1 + r) - \frac{\tilde{\beta}_{j,t} u_{c_{j,t}}}{\tilde{\beta}_{j+1,t+1} u_{c_{j+1,t+1}}} \right] \quad \forall t, j \tag{3.44}$$

The first order conditions of the government's problem, which will determine the optimal capital income tax rate in equation (3.44) are the following:

$$[c_{j,t}] \qquad \mu_{j,t} \tilde{\beta}_{j,t} V_{c_{j,t}} + \xi_t = 0 \qquad \forall t, j \tag{3.45}$$

$$[m_{j,t}] \qquad \mu_{j,t} \tilde{\beta}_{j,t} V_{m_{j,t}} + \xi_t = 0 \qquad \forall t, j \tag{3.46}$$

$$[l_{j,t}] \qquad \mu_{j,t} \tilde{\beta}_{j,t} V_{l_{j,t}} - \xi_t Y_{l_{j,t}} = 0 \qquad \forall t, j \tag{3.47}$$

$$[a_{j,t}] \qquad \theta^t \xi_t - \theta^{t+1} \xi_{t+1} \left(1 + r\right) = 0 \qquad \forall t, j \tag{3.48}$$

Forwarding (3.45) one period and substituting into (3.48) we obtain:

$$\frac{\mu_{j,t}\tilde{\beta}_{j,t}V_{c_{j,t}}}{\theta\mu_{j+1,t+1}\tilde{\beta}_{j+1,t+1}V_{c_{j+1,t+1}}} = (1+r_t) \tag{3.49}$$

Substituting (3.49) into (3.44):

$$\tau^a_{j,t} = \frac{\tilde{\beta}_{j,t}}{\tilde{\beta}_{j+1,t+1}r_t}\left[\frac{\mu_{j,t}V_{c_{j,t}}}{\theta\mu_{j+1,t+1}V_{c_{j+1,t+1}}} - \frac{u_{c_{j,t}}}{u_{c_{j+1,t+1}}}\right] \tag{3.50}$$

The optimal capital income tax is not zero since:

$$\frac{\mu_{j,t}V_{c_{j,t}}}{\theta\mu_{j+1,t+1}V_{c_{j+1,t+1}}} \neq \frac{u_{c_{j,t}}}{u_{c_{j+1,t+1}}}$$

■

This result stems from the two peculiarities of endogenous longevity described above. First, it is straightforward to show that the government weights consumption today and tommorrow differently from households, since (i) the relative weights of the generations matter and (ii) the government discounts future generations with an exogenous discount rate θ. Secondly, and more importantly, the government's marginal utility of consumption in the pseudo-utility function is not the same as the marginal utility of consumption of the household, resulting in non-zero capital income tax rates even if the government ignores cohort size and doesn't discount future generations.

Households choose consumption and leisure in order to maximize instanteneous utility and health care spending in order to maximize instanteneous and future utility. Hence the marginal utility of consumption today, is affected only by today's consumption. In contrast, in the government's problem the marginal utility of consumption takes into account the first derivative of household's utility with respect to consumption today and the *level* of utility of all subsequent periods. To see this, recall the implementability constraint when longevity is endogenous:

$$\sum_{j=1}^{J} \tilde{\beta}_{j,t} \left[u_{c_{j,t}} c_{j,t} + \tilde{u}_{m_{j,t}} m_{j,t} + u_{l_{j,t}} \left(l_{j,t+j-1} + \frac{SS_{t+j-1}}{w e^{\phi h_{j,t+j-1}}} \right) \right] = 0 \quad \forall t, j$$

As described above:

$$\tilde{u}_{m_{j,t}} = u_{j,m_{j,t}} + \sum_{i=j+1}^{J} P_{i,m_{j,t}} u_i + \sum_{i=j+1}^{J} P_i u_{i,m_{j,t}}$$

where u_i is the level of utility of cohort i. Hence, the government has an incentive to distort the consumption choices of the household, because they are not chosen optimally from the perspective of the second best allocation. An alternative interpretation of this result is that by explicitly maximizing over the number of periods the household can derive utility from, the elasticity of consumption is different from the model with exogenous longevity, reducing the distortion of the capital income tax. In the absense of lump-sum taxation, the government minimizes the overall distortion of the tax policy π and taxing capital becomes optimal, relative to the benchmark case. As in Garriga (2003), one way of affecting the household's consumption choice is by setting a non-zero capital income tax.

Another significant implication of the wedge between the government's and household's optimization with respect to consumption is that changes in longevity affect the level of the optimal capital income tax. When the probability of survival changes, it affects both the relative size of the cohorts and the discount rate of future consumption that the government maximizes over. Considering the technological improvements in the medical sector and the steady increase in life expectancy over the last centuries, with no projected slow down, this result has significant policy implications for the optimal tax structure. Not only do the relative size of capital income and labour income tax rates change with any given level of government spending, but taking into account the effects of endogenous longevity we can investigate what is the optimal financing of increasing social security and health care spending caused by increases in life expectancy, namely the ageing of the population.

Moreover, assuming that the government cannot discriminate between cohorts and is contrained in using a uniform health care spending tax, the following additional restrictions need to be imposed, by the same token as the previous analytical model, which inluence the optimal capital income tax:

$$\frac{u_{c_{1,t}}}{u_{c_{2,t+1}}} = ... = \frac{u_{c_{J-1,t}}}{c_{J,t+1}} \quad \forall t, \tag{3.51}$$

$$\frac{u_{c_{1,t}}}{u_{l_{1,t}}} e^{\phi \bar{h}_{1,t}} = ... = \frac{u_{c_{J,t}}}{u_{l_{1Jt}}} e^{\phi \bar{h}_{J,t}} \quad \forall t, j, \tag{3.52}$$

$$\frac{\tilde{\beta}_{1,t} \tilde{u}_{m_{1,t}}}{\tilde{\beta}_{1,t} u_{c_{1,t}}} = ... = \frac{\tilde{\beta}_{J,t} \tilde{u}_{m_{J,t}}}{\tilde{\beta}_{J,t} u_{c_{J,t}}} \quad \forall t, j \tag{3.53}$$

The two analytical models described above have significant policy implication for the design of the optimal tax policy, since health is a significant form on human capital which affects productivity[16], longevity and the quality of life of the households. Furthermore, a sizeble share of GDP that is allocated on health care which is projected to increase even further in the future due to the ageing of the population. This raises the question of the optimal level of health care spending, the respective level of government subsidy and the financing mechanism of these expenditures. Hence, the omission of the distortions of tax policy on health care spending, savings and labour supply can have substantial welfare and growth implications.

In the next section, we assess quantitatively the effect of health on optimal taxation

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[16] In our paper health includes both physical and mental health. Lately, the direct and indirect (through the interaction of mental and psysical health) effects of mental health have revealed the significance of mental illness on labour productivity.

in an overlapping generations model which combines the effects of health both on productivity and longevity. As an additional exercise, we study the effects of a change in expected longevity and the optimal tax policy to finance the resulting excess burden of health care spending and social security payments from an ageing population, a pressing issue in developed countries.

3.4 Quantitative Results

In order to estimate the magnitude of the two effect of health on optimal taxation, we turn to the quantitative version of our model. First, we estimate the decentralized equilibrium using the current tax policy in order to calibrate the model and assess how closely our model fits the data. Then, using the calibrated parameter values, we estimate the second best allocation and the optimal tax policy π and compare it with the actual data. Furthermore, we simulate the effects of technological progress in the medical sector, which affects longevity and estimate the optimal response of the government, considering the effects of the ageing of the population on health care spending and social security.

Finally, we estimate the optimal tax policy π with and without restrictions with respect to age-dependent taxation in order to estimate the quantitative effect of such restriction on the optimal tax system.

3.4.1 Calibration

Here, we present the functional forms and the parameter values for the decentralized equilibrium and the second best allocation, calibrated to match relevant aggregates of the UK economy. By focusing on the UK, where health care insurance is mainly publicly provided, free at the point of service and financed by general taxation, we can abstract from complicated insurance schemes without being less realistic and concentrate on aspects that are more relevant for our analysis[17].

Demographics

The maximum number of periods agents can survive is set to $J = 3$, with each period in the model corresponding to 20 years[18]. Agents enter the economy at the age of 20 and they survive maximum at the age of 80. The eligible age for pension payments in the benchmark model is set to $J_R = 2$, which means that agents receive pensions after the age of 60, although they can supply labour if they choose so. The yearly population growth is set to $n = 0.62\%$ (ONS, 2013*b*), consistent with the UK data.

Preferences

The instantaneous utility of the agent of cohort j at time t is determined by the modified utility function as proposed by Hall and Jones (2007) where we have incorporated labour supply:

$$u_{j,t} = b + \frac{c_{j,t}^{1-\gamma}}{1-\gamma} + \psi \frac{h_{j,t}^{1-\sigma}}{1-\sigma} + \nu \frac{\left(1 - l_{j,t}\right)^{1-\eta}}{1-\eta} \tag{3.1}$$

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[17] The level of health care spending tax in our model (which is always negative under all reasonable specifications) is interpreted as the share of overall health care spending that the National Health Service is willing to cover. Since co-payments in the UK do not account for a significant fraction of out-pocket payments, the level of subsidy expresses the share of medical services and pharmaceuticals that the NHS chooses to supply free of charge. In essence, a change in the subsidy level in our model corresponds to changes in the medical coverage of the population, with a subsequent increase in out-of-pocket payments, since households receive treatment in the private sector.

[18] The purpose of this exercise is to demonstrate quantitatively that the optimal capital income tax is not zero, even when the government is not restricted in using uniform tax rates across cohorts. Increasing the number of cohorts would not affect our main result but would complicate the exercise considerably given that in this chapter we obtain the second best solution, in contrast to the previous chapter where we calculate solely the decentralized equilibrium.

where b is a constant parameter[19], ψ and ν are the relative weights of health and leisure in the utility function and γ, σ and η are the coefficients of relative risk aversion of consumption and health and leisure respectively. We calibrate the parameters, presented in Table 1, drawing directly from the estimated parameter values of Hall and Jones (2007), setting $b = 66.27$, $\gamma = 2$, $\sigma = 1.051$, and $\psi = 2.396$. In the life-time maximization problem we set the agent's discount rate β to 1.01. We calibrate the parameters of leisure in order to match the labour supply of roughly one third in the data, setting $\nu = 10.5$ and $\eta = 6$.

Health and Probability of Survival

The health and probability of survival functions are described as in (3.3) and (3.4) respectively.

The values of δ_j, Q_j and z_j of the health production function are age and model specific in order to match the level of health care spending and the probability of survival in the UK economy. We assume that the value of δ_j increases with age, $\delta_j = [0, 0.7, 0.8]$, in order to reflect the health deteriorating, while Q_j and z_j remain constant to 10 and 0.6 respectively.

The parameter values of the probability of survival (3.3), a_{p_j} and b_{p_j} are set to 10 and 0.3 respectively for all cohorts. With the given health level of each cohort, we calibrate the parameter values in order to fit the UK data with respect to the survival probability.

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[19] As Rossen (1988) points out, in contrast to the standard models with exogenous probability of survival, where only marginal utility is relevant for optimal decisions, when the probability of survival is endogenous the level of utility is significant as well. In a nutshell, agents do not only decide the allocation of consumption between periods, but also the number of periods they derive utility from. However, as Hall and Jones (2007) note, in the stardard CRRA utility functions the level of utility is negative for standard values of the coefficient of relative risk aversion. In order to overcome this issue, where it is optimal for the agent to choose less periods of consumption since the sum of per period utility is negative, they add a constant parameter. The intuition of the constant parameter, is simple; the utility that the agent derives simply by being alive, ignoring consumption and the level of health.

Production Technology

The share of capital in our economy is set to $\alpha = 1/3$ (Attanasio, Kitao and Violante, 2010). The productivity enhancing parameter ϕ in $e^{\phi h_{j,t}}$ is set to 0.1 to match the household's health care spending profiles. Total factor productivity is set as $A = 1$ for normalization.

Social Security and Government Spending

We assume that the government adjust the income tax rate τ^w, in order to balance its budget and captures both income tax and social insurance contributions. The consumption tax rate, τ^c is set to 13% , τ^a is 50.2% and $\chi = 0.326$, which is the average pension replacement rate in the UK OECD (2013*a*), and $g = 0.28$ to match the level of overall government spending as a percentage of GDP. The health care spending tax rate is set to $\tau^h = -0.833$, which in turns suggests that the level of government subsidies of health care expenditure is 83.3%, close to the historical average of the UK economy ONS (2013*a*).

3.4.2 Decentralized Equilibrium and Second Best

In Table 1 we provide the UK data for key variables of interest, along with the results of the decentralized equilibrium and the second best for the restricted version of the government problem in order to obtain comparable results with the UK data and the decentralized equilibrium.

Our benchmark model fits the UK data quite well. With a given level of government subsidies on health care, which is set exogenously to reflect the actual UK policy, the medical spending chosen by the households is close to the observed health care spending to the UK (11.73% as opposed to 8.8% in the data), which results in a higher labour income tax of 36.63% as opposed to 24.8% as calculated by Uhlig (2012). This level of medical spending results in a level of health and subsequently probabilities of survival to 40 and 60 years respectively that are very close to the observed data. Thus, the percentage of GDP devoted to pensions payments (7.75%), which is influenced by the population structure and the generosity of the social security system, follows closely the actual data (8.17%)[20]. Furthermore, the savings rate in the benchmark model reflects the actual savings rate of the economy at 15.41% as opposed to 15.6% in the data. These results and the accurate calibration of the benchmark economy are crucial for the second best allocation since the savings and spending decisions of the household, together with the fiscal implications through the probability of survival and pensions affect the optimal tax policy of the government. Government spending, especially health care spending and pensions, naturally affects the level of the optimal taxation since the government budget is balanced[21].

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[20] In our model, life expectancy is slightly lower than the actual data due to the fact that we chose a three-generations model, which reduces the number of pensioners slightly.

[21] Introducing debt has important implications with respect to the optimal capital income tax, since the government can accumulate negative debt (own private capital) and partially finance government spending via capital income, decreasing the optimal capital income tax and its subsequent distortion on savings. For simplicity we abstract from this scenario in this model.

Table 3.1: Results

	Data	Decentralized	Optimal
Labour Income Tax,%	24.80	36.63	34.78
Capital Income Tax,%	50.20	50.20	7.69
Health Spending Tax,%	-83.30	-83.30	-74.31
Consumption Tax,%	13.00	13.00	13.00
Aggregate Health Spending,%GDP	8.80	11.73	3.15
Savings,%GDP	15.60	15.41	19.26
Probability of Survival to 40	98.00	98.48	98.45
Probability of Survival to 60	89.01	91.31	91.16
Labour Supply Young (Hours/Week)	36.30	41.04	42.58
Labour Supply Middle Age (Hours/Week)	36.30	25.20	18.79
Labour Supply Old (Hours/Week)	36.30	9.30	0.35
Pensions,%GDP	8.17	7.75	7.84
Government Health Spending,%GDP	7.33	9.77	2.34
Government Consumption,%GDP	28.00	28.00	28.00
Total Government Spending,%GDP	43.50	45.52	38.18

Notes: Data are collected from stat.OECD, Labour Force Survey (2013), Human Mortality Database (2014) and Trabandt and Uhlig (2011)

The most interesting results stem from the second best allocation, with an optimal health care spending subsidy of 74.31% and capital income tax of 7.69% when the government cannot make use of age dependent taxation. Since this a benchmark model, with no idiosyncratic shocks and the usual humped-shaped labour productivity age profile, the optimal capital income tax is interpreted as an additional motivation to tax capital beyond the previously mentioned factors that are studied in the literature. The level of the optimal capital income tax rate is expected to be significantly lower in this context. This results in a significantly higher savings rate in the second best compared to the decentralised equilibrium, which comes from reduced medical spending. Savings rates are increased by 3.85 percentage points compared to the decentralized equilibrium which, in addition to a significantly lower health care subsidy rate, results to lower health care spending in the second best.

In order to calculate what is the effect of uniform tax rates across cohorts we calculate the second best allocation without restricting the government with respect to age dependent tax rates.

It is optimal for the government to tax labour income more heavily for the young than the middle age (35.98% compared to 30.86%), while the most heavily taxed are the old (40.68%). As health and subsequently labour productivity falls with age, the elasticity of labour supply increases, which results in lower labour income tax rates for older cohorts. However, the old receive an exogenous pensions which is taxed at the same rate as labour income tax. Since pensions are completely inelastic, the government chooses to tax the old heavily reducing the distortionary effect of labour income taxes on the middle age and young, even if this results in lower labour supply for the old.

Health and pensions have the same effect on capital income tax, albeit to a more extreme degree, changing not only the magnitude, but the sign of capital income tax rates. Savings are more inelastic for the young, compared to the middle-age cohort since in order to smooth consumption they need to save from their higher labour income to consume in the following periods. Middle-age households not only receive less labour income, but anticipate an exogenous pension payment the next period and hence savings are very elastic. Hence the government chooses a positive income tax for the young and a subsidy for the middle-aged whose savings are inefficiently low compared to the second best allocation with age-dependent taxation.

Age-specific health care subsidies are straightforward in this model since the government finds optimal to subsidise the young more than older cohorts. A higher level of health care subsidies encourages young cohorts to invest in their level of health, which has life-cycle consequences for labour productivity, quality of life and longevity. As cohort age, this incentive becomes weaker, since their health care spending decisions at the present period affect fewer periods in the future.

Table 3.2: Age-Dependent Taxation

	Tax Rate
Labour Income Tax (Young),%	35.98
Labour Income Tax (Middle-Aged),%	30.86
Labour Income Tax (Old),%	40.68
Capital Income Tax (Young),%	2.80
Capital Income Tax (Middle-Aged),%	-15.84
Health Spending Tax (Young),%	-82.42
Health Spending Tax (Middle-Aged),%	-35.58
Health Spending Tax (Old),%	-16.49

Recall from the previous section that the inability of the government to make use of age-dependent taxation affects not only the levels of each tax rate, but the structure of the fiscal policy as well, since the optimal capital income tax becomes non-zero. The uniform tax rates (Table 3.1) are not the weighted average of their respective age-dependent counterparts (Table 3.2). A uniform capital income tax is set optimally taking into account the effects of setting a uniform labour income and health care spending tax as well, a standard result in the literature. The contribution of this paper is that with endogenous probability of survival the optimal level of capital income tax is not zero, even if we do allow the government to set the tax rates optimally without any further restrictions (Table 2) in contrast to the standard results in the literature (Garriga, 2003; Peterman, 2013).

Hence, the introduction of health in the Ramsey problem of optimal taxation has substantial effects on the optimal level of the capital income tax. In the restricted version of the government's problem, the optimal capital income tax rate is underestimated in the literature ignoring the effects of health on labour productivity and the health care spending and savings decisions of the households through the effective discount rate. In the unrestricted version of the model, the results are more interesting since the optimal capital income tax is not only non-zero but with different signs between cohorts, which complicates the optimal tax policy when the government can at least partially discriminate between cohorts[22]

3.4.3 Increased Longevity

Next we study the effect of technological progress in the medical sector that affects longevity. In our model this translates to an increase in the probability of survival for each level of health. Hence, in the function of the probability of survival (3.3) the parameter a_p increases over time[23].

Our results have significant policy implications for the challenging issue of our ageing societies and the financing of social security. Increased longevity does not only change the level of optimal taxation, as expected from increased government spending but the relative tax rates as well. Our results suggest that it is optimal to finance social security of an ageing population through increase capital income tax rates, without significantly affecting the optimal labour income tax.

TABLE 3.3: SIMULATION RESULTS

	Initial	χ	a_{p_2}
Capital Income Tax,%	7.69	7.65	9.43
Labour Income Tax,%	34.78	34.99	35.02
Health Spending Tax,%	-74.31	-74.38	-75.66
Pensions,%GDP	7.84	8.08	8.08

In order to distinguish the effects of changes in longevity on the optimal capital income tax stemming from a higher burden on social security (which is expected to change the level of capital income tax) to the changes in the *relative* tax rates we do the following

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[22] In practice, health care subsidies are not uniform, at least implicitly, since treatment in the NHS is provided taken into account the cost and benefits of the treatment which vary with age. Another example are government policies that affect labour supply on the extensive and intensive margin for older cohorts.

[23] This can be interpreted as either better treatment for life-threatening conditions or new treatments that were previously unavailable.

simulation; What are the optimal levels of capital income, labour income and health care spending tax rates after (i) increasing pensions by one percentage point (from 32.6% to 33.6%) and (ii) increasing longevity such that the fiscal impact with respect to pension payments as a percentage of GDP is identical (from $a_{p_2} = 1$ to $a_{p_2} = 1.15$). In both case the government spends 8.8% of GDP on pension paymets, up to 7.84%, however the financing of social security is significantly different (Table 3).

An increase in the pension replacement rate reduces the optimal capital income tax since agents have an incentive to save less, expecting higher future income from pensions and labour income tax increases. Partially, the increase in the labour income tax rate can be explained by the increase in the replacement ratio itself. Recall that pensions are taxed with the same tax rate as labour income and being completely inelastic, increase the optimal labour income tax rate, which is restricted to be uniform across cohorts. In contrast, with higher probability of survival, agents discount the future less, decreasing the elasticity of savings, increasing the optimal level of the optimal capital income tax rate. However, the labour income tax rate increases slightly since improvements in the medical sector increase the incentive of the government to subsidy health care spending, which raises the level of government spending more than the fiscally equivalent increase in the pension replacement rate. Better medical treatment has a dual effect on the optimal tax policy; first, the government increases health care subsidies and secondly, the elasticity of savings falls, reducing the distortions of capital income tax rates, allowing the government to finance the excess social security and health care burden with higher capital income tax rates.

Hence, the introduction of health and particularly endogenous longevity in the standard life-cycle model sheds light in another aspect of the ageing of the population largely ignored in the literature. Beyond cost containment and labour supply incentives, we can study the optimal tax policy for an ageing society not only accounting for greater costs and the corresponding increase in tax rates in order to make social security and health care system sustainable, but the optimal policy with respect to the relative weights of the tax instruments.

3.5 Conclusions

This paper studied the problem of optimal taxation in a model of health as (i) a quality of life parameter, (ii) quantity of life parameter affecting the number of periods the agents can derive utility and (iii) human capital that affects productivity. In our model the level of health is a stock that naturally deteriorates over time and agents can invest in their level of health via medical spending, which is taxed (or subsidized) by the government.

Our results suggest that incorporating health in the standard overlapping generation model affects the optimal set of government instruments substantially. Even with preferences that have the Frisch elasticity of labour supply constant over the life cycle, capital taxation is not zero if the government cannot condition all taxes on age. This result stems both from health as a form of human capital which affects the optimal level of labour income tax and the elasticity of health care spending per se, which affects the optimal health care tax rate. Hence, we contribute in the literature by considering an additional form of human capital which affects the optimal level of capital income tax, beyond incomplete insurance markets and non constant labour supply elasticity over the life cycle. Moreover, the peculiarity of health as a factor that affects longevity has implication on the optimal path of capital gains taxation. In our model, technological progress in the medical sector that affects longevity dictates an optimal *path* of capital income taxation instead of an optimal *level*.

The model could be extended in various directions. First, we focus on presenteeism, which affects the labour supply productivity and we abstract from absenteeism, namely sick time which significantly impacts the effective labour supply. Although working hours lost due to illness vary between countries, a substantial fraction of potential working hours are lost every year [24]. In addition, considering uncertainty and heterogeneity in an overlapping model with health we can study the welfare implications of optimal taxation taking into account differences in productivity, labour supply in the extensive and intensive margin and probability of survival explicitly extending the framework of Conesa, Kitao and Krueger (2009). Thus, we can study the socio-economic gradient of health observed in developed countries which reflects differences in productivity and longevity and study the optimal response of the government if the objective is to take into account unequal outcomes.

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[24] For example, in the UK 2% of working hours are lost due to illness (ONS, 2014)

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Appendix

3.A Analytical Derivations

Here I present the analytical derivations of the first order condition of the decentralized equilibrium and the second best for three versions of the model; (i) a benchmark model where both probability of survival and labour productivity are exogenous, (ii) a model where the probability of survival is endogenous and (iii) a model where labour productivity is endogenous. This exercise demonstrates the effect of health as a form on human capital on the optimal level of taxation.

We assume for simplicity that the household survives at most for two periods and derives utility from the general consumption, the level of health and disutility from labour. In addition, households work both periods, earning labour income that depends on the wage rate, the hours of work and labour productivity (when treated as endogenous) and save in the first period in order to smooth consumption. Hence, the household maximizes life-time utility:

$$U\left(c_{1,t}, l_{1,t}, h_{1,t}, c_{2,t+1}, l_{2,t+1}, h_{2,t+1}\right) = u_1\left(c_{1,t}, l_{1,t}, h_{1,t}\right) + \beta p\left(h_1\right) u_2\left(c_{2,t+1}, l_{2,t+1}, h_{2,t+1}\right) \tag{3.A.1}$$

subject to the budget constraints in period one and two respectively:

$$\left(1-\tau_1^w\right) l_{1,t} w_t e^{\varphi h_1} = c_{1,t} + \left(1+q_1\right) m_{1,t} + k_{1,t} \tag{3.A.2}$$

$$\left(1-\tau_2^w\right) l_{2,t+1} w_{t+1} e^{\varphi h_2} + \left(1 + r_t \left(1-\tau^k\right)\right) k_{1,t} = c_{2,t+1} + \left(1+q_2\right) m_{2,t+1} \tag{3.A.3}$$

3.A.1 Benchmark Model

In the benchmark model, we want to study the effect of health as a quality of life parameter, ignoring the effects of health on the probability of survival and labour productivity. The benchmark model serves as counterfactual to illuminate the channels via which health affects optimal taxation. Hence we make the following assumptions:

$$p\left(h_1\right) = \bar{p}\left(h_1\right) = 1 \tag{3.A.4}$$

$$\varphi = 0 \Rightarrow e^{\varphi h_j} = 1 \tag{3.A.5}$$

Agent's Problem

The Lagrangian of the agent's problem is expressed as:

$$\begin{aligned} L = {} & u_1\left(c_{1,t}, l_{1,t}, h_{1,t}\right) + \beta u_2\left(c_{2,t+1}, l_{2,t+1}, h_{2,t+1}\right) + \\ & + \lambda_t \left(\left(1-\tau_1^w\right) l_{1,t} w_t - c_{1,t} - \left(1+q_1\right) m_{1,t} - k_{1,t}\right) + \\ & + \lambda_{t+1} \left(\left(1-\tau_2^w\right) l_{2,t+1} w_{t+1} + \left(1 + r_t\left(1-\tau^k\right)\right) k_{1,t} - c_{2,t+1} - \left(1+q_2\right) m_{2,t+1}\right) \end{aligned} \tag{3.A.6}$$

The first order condition with respect to consumption, medical spending, labour supply and capital are the following:

$$u_{1,c_1} - \lambda_t = 0 \tag{3.A.7}$$

$$\beta u_{2,c_2} - \lambda_{t+1} = 0 \tag{3.A.8}$$

$$\tilde{u}_{1,m1} - \lambda_t \left(1 + q_1\right) = 0 \tag{3.A.9}$$

$$\beta \tilde{u}_{2,m_2} - \lambda_{t+1} \left(1 + q_2\right) = 0 \tag{3.A.10}$$

$$u_{1,l_1} + \lambda_t \left(1 - \tau_1^w\right) w_t = 0 \tag{3.A.11}$$

$$\beta u_{2,l_2} + \lambda_{t+1} \left(1 - \tau_2^w\right) w_{t+1} = 0 \tag{3.A.12}$$

$$\lambda_t - \lambda_{t+1} \left(\left(1 + r\left(1 - \tau^k\right)\right)\right) = 0 \tag{3.A.13}$$

where for simplicity we denote $u_{j,h_j} h_{j,m_j}$ with $\tilde{u}_{j,m_j}$, a convention that presents the chain rule in a more compact way.

Second Best

The government's objective is to maximize the following utility function of the agents:

$$\max \left[\sum_{t=0}^{\infty} \theta^t \left(u_1\left(c_{1,t}, l_{1,t}, h_{1,t}\right) + \beta u_2\left(c_{1,t}, l_{1,t}, h_{1,t}\right)\right)\right] \tag{3.A.14}$$

subject to the implementability constraint which takes into account the agent's budget constraints and first order conditions

$$\sum_{t=1}^{\infty} \sum_{j=1}^{2} \beta^{j-1} \left[u_{j,c_1} c_{j,t} + \tilde{u}_{j,m_j} m_{j,t} + u_{j,l_j} l_{j,t}\right] \tag{3.A.15}$$

and the resource constraint of the economy in period t and $t+1$

$$c_{1,t} + c_{2,t} + m_{1,t} + m_{2,t} + K_t + G_{t+1} - Y_t\left(K_{t-1}, L_t\right) - (1-\delta)\, K_{t-1} = 0 \tag{3.A.16}$$

and

$$\theta\left(c_{1,t+1} + c_{2,t+1} + m_{1,t+1} + m_{2,t+1} + K_{t+1} + G_{t+1} - Y_{t+1}\left(K_t, L_{t+1}\right) - (1-\delta)\, K_t\right) = 0 \tag{3.A.17}$$

Proof of the Implementability Constraint

Proof. In order to derive the implementability constraint, we first multiply the budget constraints of the agent when young and old with their respective Lagrange multiplier λ and then add up the two expressions.

$$\lambda_t c_{1,t} + \lambda_t (1+q_1) m_{1,t} - \lambda_t\left(1-\tau_1^w\right) l_{1,t} w_t = \lambda_t k_{1,t} \tag{3.A.18}$$

$$\lambda_{t+1} c_{2,t+1} + \lambda_{t+1}(1+q_2) m_{2,t+1} - \lambda_{t+1}\left(1-\tau_2^w\right) l_{2,t+1} w_{t+1} = -\lambda_{t+1} k_{1,t}\left(1 + r\left(1-\tau^k\right)\right) \tag{3.A.19}$$

$$\begin{aligned} &\lambda_t c_{1,t} + \lambda_{t+1} c_{2,t+1} + \lambda_t\left(1+q_1\right) m_{1,t} + \lambda_{t+1}(1+q_2) m_{2,t+1} - \\ &-\lambda_t\left(1-\tau_1^w\right) l_{1,t} w_t - \lambda_{t+1}\left(1-\tau_2^w\right) l_{2,t+1} w_{t+1} = \\ &= \lambda_t k_{1,t} - \lambda_{t+1} k_{1,t}\left(1 + r\left(1-\tau^k\right)\right) \end{aligned} \tag{3.A.20}$$

Finally, using the first order conditions of the agent with respect to consumption, health, labour supply and capital (3.A.7)-(3.A.13) we obtain:

$$\begin{aligned}
&u_{1,c_1} c_{1,t} + \tilde{u}_{1,m_1} m_{1,t} + u_{1,l_1} l_{1,t} + \beta u_{2,c_2} c_{2,t+1} + \beta \tilde{u}_{2,m_2} m_{2,t+1} + \beta u_{2,l_2} l_{2,t+1} = \\
&= \lambda_{t+1} \left(1 + r\left(1 - \tau^k\right)\right) k_{1,t} - \lambda_{t+1} k_{1,t} \left(1 + r\left(1 - \tau^k\right)\right)
\end{aligned} \tag{3.A.21}$$

which reduces to the standard implementability constraint:

$$u_{1,c_1} c_{1,t} + \tilde{u}_{1,m_1} m_{1,t} + u_{1,l_1} l_{1,t} + \beta u_{2,c_2} c_{2,t+1} + \beta \tilde{u}_{2,h_2} m_{2,t+1} + \beta u_{2,l_2} l_{2,t+1} = 0$$

■

The Langrangian:

$$\begin{aligned}
&L = u_1 \left(c_{1,t}, l_{1,t}, h_{1,t}\right) + \beta u_2 \left(c_{2,t+1}, l_{2,t+1}, h_{2,t+1}\right) + \\
&+\mu_t \left(u_{1,c_1} c_{1,t} + \tilde{u}_{1,m_1} m_{1,t} + u_{1,l_1} l_{1,t} + \beta u_{2,c_2} c_{2,t+1} + \beta \tilde{u}_{2,h_2} m_{2,t+1} + \beta u_{2,l_2} l_{2,t+1}\right) \\
&+\rho_t \left(c_{1,t} + c_{2,t} + m_{1,t} + m_{2,t} + K_t + G_{t+1} - Y_t \left(K_{t-1}, L_t\right) - (1-\delta) K_{t-1}\right) \\
&\theta \rho_{t+1} \left(c_{1,t+1} + c_{2,t+1} + m_{1,t+1} + m_{2,t+1} + K_{t+1} + G_{t+1} - Y_{t+1} \left(K_t, L_{t+1}\right) - (1-\delta) K_t\right)
\end{aligned} \tag{3.A.22}$$

FONC with respect to consumption, medical spending, labour supply and capital:

$$u_{1,c_1} + \mu_t \left(u_{1,c_1c_1}c_1 + u_{1,c_1}\right) - \rho_t = 0 \tag{3.A.23}$$

$$\beta u_{2c_2} + \mu_t\beta \left(u_{2,c_2c_2}c_2 + u_{2,c_2}\right) - \rho_{t+1}\theta = 0 \tag{3.A.24}$$

$$\tilde{u}_{1,m_1} + \mu_t \left(\tilde{u}_{1,m_1m_1}m_1 + \tilde{u}_{1,m_1}\right) - \rho_t = 0 \tag{3.A.25}$$

$$\beta\tilde{u}_{2,m_2} + \mu_t\beta \left(\tilde{u}_{2,m_2m_2}m_2 + \tilde{u}_{m,m_2}\right) - \rho_{t+1}\theta = 0 \tag{3.A.26}$$

$$u_{1,l_1} + \mu_t \left(u_{1,l_1l_1}l_1 + u_{1,l_1}\right) + \rho_t Y_{l_1} = 0 \tag{3.A.27}$$

$$\beta u_{2,l_2} + \mu_t\beta \left(u_{2,l_2l_2}l_2 + u_{2,l_2}\right) + \rho_t\theta Y_{l_2} = 0 \tag{3.A.28}$$

$$-\rho_t + \rho_{t+1}\theta \left(Y_{K_t} + (1-\delta)\right) = 0 \tag{3.A.29}$$

In order to obtain the optimal labour income tax rates for both cohorts we substitute the efficient allocation of consumption and labour supply obtained by the social planner's problem into:

$$(1-\tau_1^w) = -\frac{u_{1,l_1}}{u_{1,c_1}w_t} \tag{3.A.30}$$

$$(1-\tau_2^w) = -\frac{u_{2,l_2}}{u_{2,c_2}w_{t+1}} \tag{3.A.31}$$

which we obtain from re-arranging (3.A.11) and (3.A.12) in the agent's maximization problem.

In order to check whether the labour income tax rates between cohorts are equal, we take the ratio of (3.A.30) and (3.A.31):

$$\frac{1-\tau_1^w}{1-\tau_1^w} = \frac{u_{1,l_1}u_{2,c_2}}{u_{1,c_1}u_{2,l_2}} \tag{3.A.32}$$

Where from the first order condition (3.A.29) of the government's maximization problem[25]:

$$\frac{u_{1,c_1}}{u_{2,c_2}} = \frac{\beta\rho_t}{\rho_{t+1}\theta} \tag{3.A.33}$$

Proof

Combining equations (3.A.23) and (3.A.24):

$$\frac{\rho_t}{\rho_{t+1}\theta} = \frac{u_{1,c_1}+\mu_t\left(u_{1,c_1c_1}c_1+u_{1,c_1}\right)}{\beta u_{2c_2}+\beta\mu_t\left(u_{2,c_2c_2}+u_{2,c_2}\right)} \Leftrightarrow \frac{\beta\rho_t}{\rho_{t+1}\theta} = \frac{c_{1,t}^{-\gamma}+\mu_t\left(-\gamma c_{1,t}^{-\gamma}+c_{1.t}^{-\gamma}\right)}{c_{2,t+1}^{-\gamma}+\mu_t\left(-\gamma c_{2,t+1}^{-\gamma}+c_{2,t+1}^{-\gamma}\right)} = \\ = \frac{c_{1,t}^{-\gamma}(\mu_t(1-\gamma)+1)}{c_{2,t+1}^{-\gamma}(\mu_t(1-\gamma)+1)} = \left(\frac{c_{1,t}}{c_{2,t+1}}\right)^{-\gamma} = \frac{u_{1,c_1}}{u_{2,c_2}} \tag{3.A.34}$$

Hence from (3.A.32) and (3.A.33):

For the special case of CRRA utility function as in the current model:

$$\frac{1-\tau_1^w}{1-\tau_1^w} = \frac{(1+\mu_t)+\frac{v^2}{\eta}}{(1+\mu_t)+\frac{v^2}{\eta}} = 1 \tag{3.A.35}$$

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[25] This results hold only for the CRRA utility function that is separable in consumption and labour

Capital Income Tax

For the agent's and government's first order condition with respect to capital (3.A.13) and (3.A.29) respectively:

$$\left(1+r\left(1-\tau^{k}\right)\right)=\frac{\lambda_t}{\lambda_{t+1}} \Leftrightarrow \tau^{k}=\frac{1}{r}\left[(1+r)-\frac{\lambda_t}{\lambda_{t+1}}\right] \tag{3.A.36}$$

$$Y_{K_{t-1}}+1-\delta=\frac{\rho_t}{\rho_{t+1}\theta} \Leftrightarrow (1+r)=\frac{\rho_t}{\rho_{t+1}\theta} \tag{3.A.37}$$

Substituting into equation (3.A.36) the agent's first order conditions with respect to consumption (3.A.7), (3.A.8) and the interest rate relation from the government's problem (3.A.37) we obtain:

$$\tau^{k}=\frac{1}{r}\left[\frac{\rho_t}{\rho_{t+1}\theta}-\frac{u_{1,c_1}}{\beta u_{2,c2}}\right] \tag{3.A.38}$$

which implies:

$$\tau^{k}=0 \tag{3.A.39}$$

The optimal level of health care spending tax rates are determined by the agent's first order conditions (3.A.25) and (3.A.26)

$$1+q_1=\frac{\tilde{u}_{1,m_1}}{\lambda_t} \tag{3.A.40}$$

$$1+q_2=\frac{\beta\tilde{u}_{2,m_2}}{\lambda_{t+1}} \tag{3.A.41}$$

For q_j to be zero, hence there is no tax or subsidy on health care spending:

$$\tilde{u}_{1,m_1} = u_{1,c_1} \Leftrightarrow \psi \frac{z_1 \left(Q_1 m_{1,t}^{z} \right)^{1-\sigma}}{m_{1,t}} = c_{1,t}^{-\gamma} \tag{3.A.42}$$

$$\tilde{u}_{2,m_2} = u_{2,c_2} \Leftrightarrow \psi \frac{z_2 \left(Q_2 m_{2,t}^{z_2} \right)^{1-\sigma}}{m_{2,t}} = c_{2,t}^{-\gamma} \tag{3.A.43}$$

In order for the two health care tax rates to be equal (in case they are non-zero), the following relation must hold:

$$\begin{aligned} &\tfrac{1+q_1}{1+q_2} = \tfrac{\tilde{u}_{1,m_1} \beta u_{2,c_2}}{\beta \tilde{u}_{2,m_2} u_{1,c_1}} = \tfrac{\tilde{u}_{1,m_1} \rho_{t+1} \theta}{\tilde{u}_{2,m_2} \beta \rho_t} = \tfrac{\tilde{u}_{1,m_1} \rho_{t+1} \theta}{\tilde{u}_{2,m_2} \beta \rho_{t+1} \theta (1-r)} = \\ &= \tfrac{1}{\beta(1-r)} \tfrac{z_1 m_{2,t}}{z_2 m_{1,t}} \left(\tfrac{Q_1 m_{1,t}^{z}}{Q_2 m_{2,t}^{z_2}} \right)^{1-\sigma} \end{aligned} \tag{3.A.44}$$

which implies that the government has no incentive to differentiate between the two cohorts as long as:

$$\frac{\tilde{u}_{1,m_1}}{\tilde{u}_{2,m_2}} = \beta \left(1 - r \right) \tag{3.A.45}$$

When the government cannot condition health care spending taxes on age an additional constraint needs to be imposed in the government's maximization problem:

$$\frac{\tilde{u}_{1,m1}}{u_{1,c_1}} = \frac{\tilde{u}_{2,m_2}}{u_{2,c_2}} \tag{3.A.46}$$

The Lagrangian and the first order conditions respectively become:

$$
\begin{aligned}
&L = u_1\left(c_{1,t}, l_{1,t}, h_{1,t}\right) + \beta u_2\left(c_{2,t+1}, l_{2,t+1}, h_{2,t+1}\right) + \\
&+\mu_t\left(u_{1,c_1}c_{1,t} + \tilde{u}_{1,m_1}m_{1,t} + u_{1,l_1}l_{1,t} + \beta u_{2,c_2}c_{2,t+1} + \beta\tilde{u}_{2,h_2}m_{2,t+1} + \beta u_{2,l_2}l_{2,t+1}\right) + \\
&+\rho_t\left(c_{1,t} + c_{2,t} + m_{1,t} + m_{2,t} + K_t + G_{t+1} - Y_t\left(K_{t-1}, \hat{L}_t\right) - (1-\delta)K_{t-1}\right) \\
&\theta\rho_{t+1}\left(c_{1,t+1} + c_{2,t+1} + m_{1,t+1} + m_{2,t+1} + K_{t+1} + G_{t+1} - Y_{t+1}\left(K_t, \hat{L}_{t+1}\right) - (1-\delta)K_t\right) \\
&+\zeta_t\left(\tfrac{\tilde{u}_{1,m1}}{u_{1,c_1}} - \tfrac{\tilde{u}_{2,m_2}}{u_{2,c_2}}\right)
\end{aligned}
\tag{3.A.47}
$$

$$u_{1,c_1} + \mu_t\left(u_{1,c_1c_1}c_1 + u_{1,c_1}\right) - \rho_t - \zeta_t\frac{\tilde{u}_{1,m1}u_{1,c_1c_1}}{u^2_{1,c_1}} = 0 \tag{3.A.48}$$

$$\beta u_{2c_2} + \mu_t\beta\left(u_{2,c_2c_2}c_2 + u_{2,c_2}\right) - \rho_{t+1}\theta - \zeta_t\frac{\tilde{u}_{2,m_2}u_{2,c_2c_2}}{u^2_{2,c_2}} = 0 \tag{3.A.49}$$

$$\tilde{u}_{1,m_1} + \mu_t\left(\tilde{u}_{1,m_1m_1}m_1 + \tilde{u}_{1,m_1}\right) - \rho_t + \zeta_t\frac{\tilde{u}_{1,m_1m_1}}{u_{1,c_1}} = 0 \tag{3.A.50}$$

$$\beta\tilde{u}_{2,m_2} + \mu_t\beta\left(\tilde{u}_{2,m_2m_2}m_2 + \tilde{u}_{m,m_2}\right) - \rho_{t+1}\theta + \zeta_t\frac{\tilde{u}_{2,m_2m_2}}{u_{2,c_2}} = 0 \tag{3.A.51}$$

$$u_{1,l_1} + \mu_t\left(u_{1,l_1l_1}l_1 + u_{1,l_1}\right) + \rho_t Y_{l_1} = 0 \tag{3.A.52}$$

$$\beta u_{2,l_2} + \mu_t\beta\left(u_{2,l_2l_2}l_2 + u_{2,l_2}\right) + \rho_t\theta Y_{l_2} = 0 \tag{3.A.53}$$

$$-\rho_t + \rho_{t+1}\theta\left(Y_{K_t} + (1-\delta)\right) = 0 \tag{3.A.54}$$

From (3.A.48) and (3.A.49):

$$\frac{u_{1,c_1} + \mu_t\left(u_{1,c_1c_1}c_1 + u_{1,c_1}\right) - \zeta_t\frac{\tilde{u}_{1,m1}u_{1,c_1c_1}}{u^2_{1,c_1}}}{\beta u_{2c_2} + \mu_t\beta\left(u_{2,c_2c_2}c_2 + u_{2,c_2}\right) - \zeta_t\frac{\tilde{u}_{2,m_2}u_{2,c_2c_2}}{u^2_{2,c_2}}} = \frac{\rho_t}{\rho_{t+1}\theta} \tag{3.A.55}$$

which with (3.A.54) it becomes:

$$\frac{u_{1,c_1} + \mu_t \left(u_{1,c_1c_1} c_1 + u_{1,c_1}\right) - \zeta_t \frac{\tilde{u}_{1,m1} u_{1,c_1c_1}}{u_{1,c_1}^2}}{\beta u_{2c_2} + \mu_t \beta \left(u_{2,c_2c_2} c_2 + u_{2,c_2}\right) - \zeta_t \frac{\tilde{u}_{2,m_2} u_{2,c_2c_2}}{u_{2,c_2}^2}} = 1 + r \tag{3.A.56}$$

The capital income tax is now:

$$\tau^k = \frac{1}{r} \left[\frac{u_{1,c_1} + \mu_t \left(u_{1,c_1c_1} c_1 + u_{1,c_1}\right) - \zeta_t \frac{\tilde{u}_{1,m1} u_{1,c_1c_1}}{u_{1,c_1}^2}}{\beta u_{2c_2} + \mu_t \beta \left(u_{2,c_2c_2} c_2 + u_{2,c_2}\right) - \zeta_t \frac{\tilde{u}_{2,m_2} u_{2,c_2c_2}}{u_{2,c_2}^2}} - \frac{u_{1,c_1}}{\beta u_{2,c_2}} \right] \neq 0 \tag{3.A.57}$$

3.A.2 Probability of Survival

Here we assume that the probability of survival is not constant to one, but endogenous and depends on the the level of health. Hence, the household takes into account the effects of current health care spending on the probability of survival.

Lagrangian of the agent's problem becomes:

$$\begin{aligned}
\mathcal{L} = {} & u_1 \left(c_{1,t}, l_{1,t}, h_{1,t}\right) + \beta p \left(h_{1,t}\right) u_2 \left(c_{2,t+1}, l_{2,t+1}, h_{2,t+1}\right) + \\
& + \lambda_t \left(\left(1 - \tau_1^w\right) l_{1,t} w_t - c_{1,t} - \left(1 + q_1\right) m_{1,t} - k_{1,t}\right) \\
& + \lambda_{t+1} \left(\left(1 - \tau_2^w\right) l_{2,t+1} w_{t+1} + \left(1 + r_t \left(1 - \tau^k\right)\right) k_{1,t} - c_{2,t+1} - \left(1 + q_2\right) m_{2,t+1}\right)
\end{aligned} \tag{3.A.58}$$

The first order condition with respect to consumption, medical spending, labour supply and capital are the following:

$$u_{1,c_1} - \lambda_t = 0 \tag{3.A.59}$$

$$\beta p\left(h_{1,t}\right) u_{2,c_2} - \lambda_{t+1} = 0 \tag{3.A.60}$$

$$\tilde{u}_{1,m1} + \beta u_2 \tilde{p}_{m_1} - \lambda_t\left(1+q_1\right) = 0 \tag{3.A.61}$$

$$\beta p\left(h_{1,t}\right) \tilde{u}_{2,m_2} - \lambda_{t+1}\left(1+q_2\right) = 0 \tag{3.A.62}$$

$$u_{1,l_1} + \lambda_t\left(1-\tau_1^w\right) w_t = 0 \tag{3.A.63}$$

$$\beta p\left(h_{1,t}\right) u_{2,l_2} + \lambda_{t+1}\left(1-\tau_2^w\right) w_{t+1} = 0 \tag{3.A.64}$$

$$\lambda_t - \lambda_{t+1}\left(\left(1+r\left(1-\tau^k\right)\right)\right) = 0 \tag{3.A.65}$$

The government's objective is to maximize the following utility function of the agents:

$$\max\left[\sum_{t=0}^{\infty} \theta^t\left(u_1\left(c_{1,t}, l_{1,t}, h_{1,t}\right) + \beta p\left(h_{1,t}\right) u_2\left(c_{1,t}, l_{1,t}, h_{1,t}\right)\right)\right] \tag{3.A.66}$$

subject to the implementability constraint which takes into account the agent's budget constraints and first order conditions

$$\begin{aligned} &u_{1,c_1} c_{1,t} + \left(\tilde{u}_{1,m_1} + \beta u_2 \tilde{p}_{m_1}\right) m_{1,t} + u_{1,l_1} l_{1,t} + \\ &+\beta p\left(h_{1,t}\right)\left(u_{2,c_2} c_{2,t+1} + \tilde{u}_{2,m_2} m_{2,t+1} + u_{2,l_2} l_{2,t+1}\right) = 0 \end{aligned} \tag{3.A.67}$$

and the resource constraint of the economy in period t and $t+1$

$$c_{1,t} + c_{2,t} + m_{1,t} + m_{2,t} + K_t + G_{t+1} - Y_t\left(K_{t-1}, L_t\right) - (1-\delta) K_{t-1} = 0 \tag{3.A.68}$$

and

$$\theta\left(c_{1,t+1} + c_{2,t+1} + m_{1,t+1} + m_{2,t+1} + K_{t+1} + G_{t+1} - Y_{t+1}\left(K_t, L_{t+1}\right) - (1-\delta) K_t\right) = 0 \tag{3.A.69}$$

Proof of the Implemetability Constraint

Proof.

$$\lambda_t c_{1,t} + \lambda_t (1+q_1) m_{1,t} - \lambda_t \left(1-\tau_1^w\right) l_{1,t} w_t = \lambda_t k_{1,t} \tag{3.A.70}$$

$$\lambda_{t+1} c_{2,t+1} + \lambda_{t+1} (1+q_2) m_{2,t+1} - \lambda_{t+1} \left(1-\tau_2^w\right) l_{2,t+1} w_{t+1} = -\lambda_{t+1} k_{1,t} \left(1 + r\left(1-\tau^k\right)\right) \tag{3.A.71}$$

$$\begin{aligned} &\lambda_t c_{1,t} + \lambda_{t+1} c_{2,t+1} + \lambda_t \left(1+q_1\right) m_{1,t} + \lambda_{t+1} (1+q_2) m_{2,t+1} - \\ &-\lambda_t \left(1-\tau_1^w\right) l_{1,t} w_t - \lambda_{t+1} \left(1-\tau_2^w\right) l_{2,t+1} w_{t+1} = \\ &= \lambda_t k_{1,t} - \lambda_{t+1} k_{1,t} \left(1 + r\left(1-\tau^k\right)\right) \end{aligned} \tag{3.A.72}$$

Finally, using the first order conditions of the agent with respect to consumption, health, labour supply and capital (3.A.59)-(3.A.65) we obtain:

$$\begin{aligned} &u_{1,c_1} c_{1,t} + \left(\tilde{u}_{1,m_1} + \beta u_2 \tilde{p}_{m_1}\right) m_{1,t} + u_{1,l_1} l_{1,t} + \\ &+\beta p\left(h_{1,t}\right) \left(u_{2,c_2} c_{2,t+1} + \tilde{u}_{2,m_2} m_{2,t+1} + u_{2,l_2} l_{2,t+1}\right) = \\ &= \lambda_{t+1} \left(1 + r\left(1-\tau^k\right)\right) k_{1,t} - \lambda_{t+1} k_{1,t} \left(1 + r\left(1-\tau^k\right)\right) \end{aligned} \tag{3.A.73}$$

which reduces to:

$$\begin{aligned} &u_{1,c_1} c_{1,t} + \left(\tilde{u}_{1,m_1} + \beta u_2 \tilde{p}_{m_1}\right) m_{1,t} + u_{1,l_1} l_{1,t} + \\ &+\beta p\left(h_{1,t}\right) \left(u_{2,c_2} c_{2,t+1} + \tilde{u}_{2,m_2} m_{2,t+1} + u_{2,l_2} l_{2,t+1}\right) = 0 \end{aligned}$$

■

The Lagrangian of the government's problem:

$$\begin{aligned}
&L = u_1\left(c_{1,t}, l_{1,t}, h_{1,t}\right) + \beta\left(h_{1,t}\right) u_2\left(c_{2,t+1}, l_{2,t+1}, h_{2,t+1}\right) + \\
&\quad + \mu_t\left(u_{1,c_1} c_{1,t} + \left(\tilde{u}_{1,m_1} + \beta u_2 \tilde{p}_{m_1}\right) m_{1,t} + u_{1,l_1} l_{1,t}\right) + \\
&\quad + \mu_t\left(\beta p\left(h_{1,t}\right)\left(u_{2,c_2} c_{2,t+1} + \tilde{u}_{2,m_2} m_{2,t+1} + u_{2,l_2} l_{2,t+1}\right)\right) + \\
&+ \rho_t\left(c_{1,t} + c_{2,t} + m_{1,t} + m_{2,t} + K_t + G_{t+1} - Y_t\left(K_{t-1}, L_t\right) - (1-\delta) K_{t-1}\right) \\
&\theta \rho_{t+1}\left(c_{1,t+1} + c_{2,t+1} + m_{1,t+1} + m_{2,t+1} + K_{t+1} + G_{t+1} - Y_{t+1}\left(K_t, L_{t+1}\right) - (1-\delta) K_t\right)
\end{aligned} \tag{3.A.74}$$

FONC with respect to consumption, medical spending, labour supply and capital:

$$u_{1,c_1} + \mu_t\left(u_{1,c_1c_1} c_1 + u_{1,c_1}\right) - \rho_t = 0 \tag{3.A.75}$$

$$\beta p\left(h_{1,t}\right) u_{2c_2} + \mu_t \beta p\left(h_{1,t}\right)\left(u_{2,c_2c_2} c_2 + u_{2,c_2}\right) + \beta u_{2,c_2} \tilde{p}_{m_1} - \rho_{t+1}\theta = 0 \tag{3.A.76}$$

$$\tilde{u}_{1,m_1} + \beta u_2 \tilde{p}_{m_1} + \mu_t\left(\tilde{u}_{1,m_1m_1} m_1 + \tilde{u}_{1,m_1} + \beta u_2 \tilde{p}_{m_1m_1} + \beta u_2 \tilde{p}_{m_1}\right) - \rho_t = 0 \tag{3.A.77}$$

$$\beta p\left(h_{1,t}\right) \tilde{u}_{2,m_2} + \mu_t \beta p\left(h_{1,t}\right)\left(\tilde{u}_{2,m_2m_2} m_2 + \tilde{u}_{m,m_2}\right) - \rho_{t+1}\theta = 0 \tag{3.A.78}$$

$$u_{1,l_1} + \mu_t\left(u_{1,l_1l_1} l_1 + u_{1,l_1}\right) + \rho_t Y_{l_1} = 0 \tag{3.A.79}$$

$$\beta p\left(h_{1,t}\right) u_{2,l_2} + \mu_t \beta p\left(h_{1,t}\right)\left(u_{2,l_2l_2} l_2 + u_{2,l_2}\right) + \rho_t \theta Y_{l_2} = 0 \tag{3.A.80}$$

$$-\rho_t + \rho_{t+1}\theta\left(Y_{K_t} + (1-\delta)\right) = 0 \tag{3.A.81}$$

Combining equations (3.A.75) and (3.A.76):

$$\begin{aligned}
&\frac{\rho_t}{\rho_{t+1}\theta} = \frac{u_{1,c_1} + \mu_t\left(u_{1,c_1c_1} c_1 + u_{1,c_1}\right)}{\beta p(h_{1,t}) u_{2c_2} + \mu_t \beta p(h_{1,t})\left(u_{2,c_2c_2} c_2 + u_{2,c_2}\right) + \beta u_{2,c_2} \tilde{p}_{m_1}} \Leftrightarrow \\
&\Leftrightarrow \frac{\beta p(h_{1,t})\rho_t}{\rho_{t+1}\theta} = \frac{c_{1,t}^{-\gamma} + \mu_t\left(-\gamma c_{1,t}^{-\gamma} + c_{1,t}^{-\gamma}\right)}{c_{2,t+1}^{-\gamma} + \mu_t\left(-\gamma c_{2,t+1}^{-\gamma} + c_{2,t+1}^{-\gamma}\right) + \beta c_{2,t+1}^{-\gamma} \tilde{p}_{m_1}} \Leftrightarrow \\
&\Leftrightarrow \frac{\beta p(h_{1,t})\rho_t}{\rho_{t+1}\theta} = \frac{c_{1,t}^{-\gamma}\left(\mu_t(1-\gamma+1)\right)}{c_{2,t+1}^{-\gamma}\left(\mu_t(1-\gamma+1)\right) + \beta c_{2,t+1}^{-\gamma} \tilde{p}_{m_1}} \neq \frac{u_{1,c_1}}{u_{2,c_2}}
\end{aligned} \tag{3.A.82}$$

The term $\beta c_{2,t+1}^{-\gamma} \tilde{p}_{m_1}$ creates a wedge between the government's and agent's ratio of marginal utility between today and tomorrow, resulting in a non-zero capital income tax. The reason behind this result becomes clearer from the agent's and government's first order condition with respect to capital (3.A.65) and (3.A.79) respectively:

$$\left(1+r\left(1-\tau^{k}\right)\right)=\frac{\lambda_{t}}{\lambda_{t+1}}\Leftrightarrow\tau^{k}=\frac{1}{r}\left[(1+r)-\frac{\lambda_{t}}{\lambda_{t+1}}\right] \tag{3.A.83}$$

$$Y_{K_{t-1}}+1-\delta=\frac{\rho_{t}}{\rho_{t+1}\theta}\Leftrightarrow(1+r)=\frac{\rho_{t}}{\rho_{t+1}\theta} \tag{3.A.84}$$

Substituting into equation (3.A.83) the agent's first order conditions with respect to consumption (3.A.59), (3.A.60) and the interest rate relation from the government's problem (3.A.84) we obtain:

$$\begin{aligned}\tau^{k}&=\tfrac{1}{r}\left[\tfrac{\rho_{t}}{\rho_{t+1}\theta}-\tfrac{u_{1,c_{1}}}{\beta p(h_{1,t})u_{2,c2}}\right]=\\&=\left[\tfrac{c_{1,t}^{-\gamma}(\mu_{t}(1-\gamma+1))}{\beta p(h_{1,t})\left(c_{2,t+1}^{-\gamma}(\mu_{t}(1-\gamma+1))+\beta c_{2,t+1}^{-\gamma}\tilde{p}_{m_{1}}\right)}-\tfrac{u_{1,c_{1}}}{\beta p(h_{1,t})u_{2,c2}}\right]\neq0\end{aligned} \tag{3.A.85}$$

Hence the government has an incentive to distort the consumption path of the household in order to maximize life-time utility. In essence, the introduction of endogenous life expectancy creates an externality with respect to the second period consumption that the government is trying to internalize with a non-zero capital income tax.

With respect to the optimal level of health care spending subsidies:

$$(1+q_{1})=\frac{\tilde{u}_{1,m1}+\beta u_{2}\tilde{p}_{m_{1}}}{\lambda_{t}} \tag{3.A.86}$$

$$(1+q_{2})=\frac{\beta p\left(h_{1,t}\right)\tilde{u}_{2,m_{2}}}{\lambda_{t+1}} \tag{3.A.87}$$

For q_j to be zero:

$$\begin{aligned}&\tilde{u}_{1,m_1}+\beta u_2\tilde{p}_{m_1}=u_{1,c_1}\Leftrightarrow\\&\Leftrightarrow\psi\frac{z_1\left(Q_1m_{1,t}^{z}\right)^{1-\sigma}}{m_{1,t}}+\beta\left(b+\frac{c_{2,t+1}^{1-\gamma}}{1-\gamma}+\psi\frac{h_{2,t+1}^{1-\sigma}}{1-\sigma}-\nu\frac{l_{2,t+1}^{1+\frac{1}{\eta}}}{1+\frac{1}{\eta}}\right)\left(-a_pb_pz_1Q_1m_{1,t}^{z-1}e^{\left(a_pQ_1m_{1,t}^{z_1}\right)^{b_p}}\right)=c_{1,t}^{-\gamma}\end{aligned}\tag{3.A.88}$$

$$\tilde{u}_{2,m_2}=u_{2,c_2}\Leftrightarrow\psi\frac{z_2\left(Q_2m_{2,t}^{z_2}\right)^{1-\sigma}}{m_{2,t}}=c_{2,t}^{-\gamma}\tag{3.A.89}$$

The ratio of the two health care spending tax rates is denoted as:

$$\begin{aligned}&\frac{1+q_1}{1+q_2}=\frac{\tilde{u}_{1,m_1}\beta u_{2,c_2}}{\beta p(h_{1,t})\tilde{u}_{2,m_2}u_{1,c_1}}=\frac{\tilde{u}_{1,m_1}\rho_{t+1}\theta}{\tilde{u}_{2,m_2}\beta p(h_{1,t})\rho_t}=\frac{\tilde{u}_{1,m_1}\rho_{t+1}\theta}{\tilde{u}_{2,m_2}\beta p(h_{1,t})\rho_{t+1}\theta(1+r)}=\\&=\frac{1}{\beta p(h_{1,t})(1+r)}\frac{\tilde{u}_{1,m_1}+\beta u_2\tilde{p}_{m_1}}{\tilde{u}_{2,m_2}}=\\&\frac{\psi\frac{z_1\left(Q_1m_{1,t}^{z}\right)^{1-\sigma}}{m_{1,t}}+\beta\left(b+\frac{c_{2,t+1}^{1-\gamma}}{1-\gamma}+\psi\frac{h_{2,t+1}^{1-\sigma}}{1-\sigma}-\nu\frac{l_{2,t+1}^{1+\frac{1}{\eta}}}{1+\frac{1}{\eta}}\right)\left(-a_pb_pz_1Q_1m_{1,t}^{z-1}e^{\left(a_pQ_1m_{1,t}^{z_1}\right)^{b_p}}\right)}{\beta p(h_{1,t})(1+r)\psi\frac{z_2\left(Q_2m_{2,t}^{z_2}\right)^{1-\sigma}}{m_{2,t}}}\end{aligned}\tag{3.A.90}$$

3.A.3 Endogenous Productivity

The Lagrangian of the problem is expressed as:

$$\begin{aligned}L=&\,u_1\left(c_{1,t},l_{1,t},h_{1,t}\right)+\beta u_2\left(c_{2,t+1},l_{2,t+1},h_{2,t+1}\right)+\\&+\lambda_t\left(\left(1-\tau_1^w\right)l_{1,t}e^{\varphi h_1}w_t-c_{1,t}-\left(1+q_1\right)m_{1,t}-k_{1,t}\right)\\&+\lambda_{t+1}\left(\left(1-\tau_2^w\right)l_{2,t+1}e^{\varphi h_2}w_{t+1}+\left(1+r_t\left(1-\tau^k\right)\right)k_{1,t}-c_{2,t+1}-\left(1+q_2\right)m_{2,t+1}\right)\end{aligned}\tag{3.A.91}$$

The first order condition with respect to consumption, medical spending, labour supply and capital when the agent does not take into account the effect of health on productivity are the following:

$$u_{1,c_1} - \lambda_t = 0 \tag{3.A.92}$$

$$\beta u_{2,c_2} - \lambda_{t+1} = 0 \tag{3.A.93}$$

$$\tilde{u}_{1,m1} - \lambda_t \left(1 + q_1\right) = 0 \tag{3.A.94}$$

$$\beta \tilde{u}_{2,m_2} - \lambda_{t+1} \left(1 + q_2\right) = 0 \tag{3.A.95}$$

$$u_{1,l_1} + \lambda_t \left(1 - \tau_1^w\right) e^{\varphi h_1} w_t = 0 \tag{3.A.96}$$

$$\beta u_{2,l_2} + \lambda_{t+1} \left(1 - \tau_2^w\right) e^{\varphi h_2} w_{t+1} = 0 \tag{3.A.97}$$

$$\lambda_t - \lambda_{t+1} \left(\left(1 + r\left(1 - \tau^k\right)\right)\right) = 0 \tag{3.A.98}$$

When the agent takes into account endogenous productivity:

$$u_{1,c_1} - \lambda_t = 0 \tag{3.A.99}$$

$$\beta u_{2,c_2} - \lambda_{t+1} = 0 \tag{3.A.100}$$

$$\tilde{u}_{1,m1} + \lambda_t \left[\left(1 - \tau_1^w\right) l_{1,t} w_t \varphi h_{1,m_1} e^{\varphi h_1} - \left(1 + q_1\right)\right] = 0 \tag{3.A.101}$$

$$\beta \tilde{u}_{2,m_2} + \lambda_t \left[\left(1 - \tau_2^w\right) l_{2,t+1} w_{t+1} \varphi h_{2,m_2} e^{\varphi h_2} - \left(1 + q_2\right)\right] = 0 \tag{3.A.102}$$

$$u_{1,l_1} + \lambda_t \left(1 - \tau_1^w\right) e^{\varphi h_1} w_t = 0 \tag{3.A.103}$$

$$\beta u_{2,l_2} + \lambda_{t+1} \left(1 - \tau_2^w\right) e^{\varphi h_2} w_{t+1} = 0 \tag{3.A.104}$$

$$\lambda_t - \lambda_{t+1} \left(\left(1 + r\left(1 - \tau^k\right)\right)\right) = 0 \tag{3.A.105}$$

Second Best

The government's objective is to maximize the following utility function of the agents:

$$\max \left[\sum_{t=0}^{\infty} \theta^t \left(u_1\left(c_{1,t}, l_{1,t}, h_{1,t}\right) + \beta u_2\left(c_{1,t}, l_{1,t}, h_{1,t}\right)\right)\right] \tag{3.A.106}$$

subject to the implementability constraint which takes into account the agent's budget constraints and first order conditions, which for the first case, it is the standard implementability constraint:

$$u_{1,c_1}c_{1,t} + \tilde{u}_{1,m_1}m_{1,t} + u_{1,l_1}l_{1,t} + \beta u_{2,c_2}c_{2,t+1} + \beta \tilde{u}_{2,h_2}m_{2,t+1} + \beta u_{2,l_2}l_{2,t+1} = 0 \quad (3.A.107)$$

and when the agents take into account the effects of health on productivity:

$$\begin{aligned} & u_{1,c_1}c_{1,t} + \left(\tilde{u}_{1,m1} - u_{1,l_1}\varphi h_{1,m_1}l_{1,t}\right)m_{1,t} + u_{1,l_1}l_{1,t} + \\ & +\beta\left(u_{2,c_2}c_{2,t+1} + \left(\tilde{u}_{2,m_2} - u_{2,l_2}\varphi h_{2,m_2}l_{2,t+1}\right)m_{2,t+1} + u_{2,l_2}l_{2,t+1}\right) = 0 \end{aligned} \quad (3.A.108)$$

and the resource constraint of the economy in period t and $t+1$

$$c_{1,t} + c_{2,t} + m_{1,t} + m_{2,t} + K_t + G_{t+1} - Y_t\left(K_{t-1}, \hat{L}_t\right) - (1-\delta)K_{t-1} = 0 \quad (3.A.109)$$

and

$$\theta\left(c_{1,t+1} + c_{2,t+1} + m_{1,t+1} + m_{2,t+1} + K_{t+1} + G_{t+1} - Y_{t+1}\left(K_t, \hat{L}_{t+1}\right) - (1-\delta)K_t\right) = 0 \quad (3.A.110)$$

Proof of the Implementability Constraint

Proof.

$$\lambda_t c_{1,t} + \lambda_t(1+q_1)m_{1,t} - \lambda_t\left(1-\tau_1^w\right)l_{1,t}w_t e^{\varphi h_1} = \lambda_t k_{1,t} \quad (3.A.111)$$

$$\lambda_{t+1}c_{2,t+1}+\lambda_{t+1}(1+q_2)m_{2,t+1}-\lambda_{t+1}\left(1-\tau_2^w\right)l_{2,t+1}w_{t+1}e^{\varphi h_2}=\lambda_{t+1}k_{1,t}\left(1+r\left(1-\tau^k\right)\right) \tag{3.A.112}$$

For the first case, where the agent do not take into account the effects of health on productivity, the implementability constraint remains the same as the implementability constraint of the the model with health in the utility:

$$u_{1,c_1}c_{1,t}+\tilde{u}_{1,m_1}m_{1,t}+u_{1,l_1}l_{1,t}+\beta u_{2,c_2}c_{2,t+1}+\beta\tilde{u}_{2,h_2}m_{2,t+1}+\beta u_{2,l_2}l_{2,t+1}=0$$

However, when agents take into account the effects of health on productivity, the implementability constraint becomes:

$$\begin{aligned}&u_{1,c_1}c_{1,t}+\left(\tilde{u}_{1,m1}-u_{1,l_1}\varphi h_{1,m_1}l_{1,t}\right)m_{1,t}+u_{1,l_1}l_{1,t}+\\&+\beta\left(u_{2,c_2}c_{2,t+1}+\left(\tilde{u}_{2,m_2}-u_{2,l_2}\varphi h_{2,m_2}l_{2,t+1}\right)m_{2,t+1}+u_{2,l_2}l_{2,t+1}\right)=0\end{aligned}$$

■

The Langrangian:

$$\begin{aligned}&L=u_1\left(c_{1,t},l_{1,t},h_{1,t}\right)+\beta u_2\left(c_{2,t+1},l_{2,t+1},h_{2,t+1}\right)+\\&+\mu_t\left(u_{1,c_1}c_{1,t}+\tilde{u}_{1,m_1}m_{1,t}+u_{1,l_1}l_{1,t}+\beta u_{2,c_2}c_{2,t+1}+\beta\tilde{u}_{2,h_2}m_{2,t+1}+\beta u_{2,l_2}l_{2,t+1}\right)\\&+\rho_t\left(c_{1,t}+c_{2,t}+m_{1,t}+m_{2,t}+K_t+G_{t+1}-Y_t\left(K_{t-1},\hat{L}_t\right)-(1-\delta)K_{t-1}\right)\\&\theta\rho_{t+1}\left(c_{1,t+1}+c_{2,t+1}+m_{1,t+1}+m_{2,t+1}+K_{t+1}+G_{t+1}-Y_{t+1}\left(K_t,\hat{L}_{t+1}\right)-(1-\delta)K_t\right)\end{aligned} \tag{3.A.113}$$

FONC with respect to consumption, medical spending, labour supply and capital:

$$u_{1,c_1} + \mu_t \left(u_{1,c_1c_1} c_1 + u_{1,c_1}\right) - \rho_t = 0 \tag{3.A.114}$$

$$\beta u_{2c_2} + \mu_t \beta \left(u_{2,c_2c_2} c_2 + u_{2,c_2}\right) - \rho_{t+1}\theta = 0 \tag{3.A.115}$$

$$\begin{aligned} &\tilde{u}_{1,m_1} + \mu_t \left(\tilde{u}_{1,m_1m_1} m_1 + \tilde{u}_{1,m_1}\right) - \\ &-\rho_t \left[(1-a) A \varphi l_{1,t} Q_1 z_1 K^a m_1^{z-1} e^{\varphi h_{1,t}} \left(l_{1,t} e^{\varphi h_{1,t}} + l_{2,t} e^{\varphi h_{2,t}}\right)\right] = 0 \end{aligned} \tag{3.A.116}$$

$$\begin{aligned} &\beta \tilde{u}_{2,m_2} + \mu_t \beta \left(\tilde{u}_{2,m_2m_2} m_2 + \tilde{u}_{m,m_2}\right) - \\ &-\rho_{t+1}\theta \left[(1-a) A \varphi l_{2,t+1} Q_2 z_2 K^a m_{2+1}^{z_2-1} e^{\varphi h_{2,t+1}} \left(l_{1,t+1} e^{\varphi h_{1,t+1}} + l_{2,t+1} e^{\varphi h_{2,t+1}}\right)\right] = 0 \end{aligned} \tag{3.A.117}$$

$$u_{1,l_1} + \mu_t \left(u_{1,l_1l_1} l_1 + u_{1,l_1}\right) + \rho_t Y_{l_1} = 0 \tag{3.A.118}$$

$$\beta u_{2,l_2} + \mu_t \beta \left(u_{2,l_2l_2} l_2 + u_{2,l_2}\right) + \rho_t \theta Y_{l_2} = 0 \tag{3.A.119}$$

$$-\rho_t + \rho_{t+1}\theta \left(Y_{K_t} + (1-\delta)\right) = 0 \tag{3.A.120}$$

When the agent takes into account the effect of health on productivity:

$$\begin{aligned} &L = u_1 \left(c_{1,t}, l_{1,t}, h_{1,t}\right) + \beta u_2 \left(c_{2,t+1}, l_{2,t+1}, h_{2,t+1}\right) + \\ &+\mu_t \left(\begin{array}{l} u_{1,c_1} c_{1,t} + \left(\tilde{u}_{1,m1} - u_{1,l_1} \varphi h_{1,m_1} l_{1,t}\right) m_{1,t} + u_{1,l_1} l_{1,t} + \\ +\beta \left(u_{2,c_2} c_{2,t+1} + \left(\tilde{u}_{2,m_2} - u_{2,l_2} \varphi h_{2,m_2} l_{2,t+1}\right) m_{2,t+1} + u_{2,l_2} l_{2,t+1}\right) \end{array} \right) \\ &+\rho_t \left(c_{1,t} + c_{2,t} + m_{1,t} + m_{2,t} + K_t + G_{t+1} - Y_t \left(K_{t-1}, \hat{L}_t\right) - (1-\delta) K_{t-1}\right) \\ &\theta \rho_{t+1} \left(c_{1,t+1} + c_{2,t+1} + m_{1,t+1} + m_{2,t+1} + K_{t+1} + G_{t+1} - Y_{t+1} \left(K_t, \hat{L}_{t+1}\right) - (1-\delta) K_t\right) \end{aligned} \tag{3.A.121}$$

FONC with respect to consumption, medical spending, labour supply and capital:

$$u_{1,c_1} + \mu_t \left(u_{1,c_1 c_1} c_1 + u_{1,c_1} \right) - \rho_t = 0 \tag{3.A.122}$$

$$\beta u_{2c_2} + \mu_t \beta \left(u_{2,c_2 c_2} c_2 + u_{2,c_2} \right) - \rho_{t+1} \theta = 0 \tag{3.A.123}$$

$$\begin{aligned} &\tilde{u}_{1,m_1} + \mu_t \left(\tilde{u}_{1,m_1 m_1} m_1 + \tilde{u}_{1,m_1} - u_{1,l_1} \varphi h_{1,m_1 m_1} l_{1,t} m_{1,t} - u_{1,l_1} \varphi h_{1,m_1} l_{1,t} \right) - \\ &-\rho_t \left[(1-a) A \varphi l_{1,t} Q_1 z_1 K^a m_1^{z-1} e^{\varphi h_{1,t}} \left(l_{1,t} e^{\varphi h_{1,t}} + l_{2,t} e^{\varphi h_{2,t}} \right) \right] = 0 \end{aligned} \tag{3.A.124}$$

$$\begin{aligned} &\beta \tilde{u}_{2,m_2} + \mu_t \beta \left(\tilde{u}_{2,m_2 m_2} m_2 + \tilde{u}_{m,m_2} - u_{2,l_2} \varphi h_{2,m_2 m_2} l_{2,t+1} m_{2,t+1} - u_{2,l_2} \varphi h_{2,m_2} l_{2,t+1} \right) - \\ &-\rho_{t+1} \theta \left[(1-a) A \varphi l_{2,t+1} Q_2 z_2 K^a m_{2+1}^{z_2-1} e^{\varphi h_{2,t+1}} \left(l_{1,t+1} e^{\varphi h_{1,t+1}} + l_{2,t+1} e^{\varphi h_{2,t+1}} \right) \right] = 0 \end{aligned} \tag{3.A.125}$$

$$u_{1,l_1} + \mu_t \left(u_{1,l_1 l_1} l_1 + u_{1,l_1} \right) + \rho_t Y_{l_1} = 0 \tag{3.A.126}$$

$$\beta u_{2,l_2} + \mu_t \beta \left(u_{2,l_2 l_2} l_2 + u_{2,l_2} \right) + \rho_t \theta Y_{l_2} = 0 \tag{3.A.127}$$

$$-\rho_t + \rho_{t+1} \theta \left(Y_{K_t} + (1-\delta) \right) = 0 \tag{3.A.128}$$

It is trivial to show that even if labour productivity is endogenous and irrespectively of whether the agents take into account the effects of medical spending on their labour productivity, the optimal capital income tax rate is zero. The first order conditions of the household and the government with respect to consumption are identical to the benchmark model, which as proven above results in a zero optimal capital income tax. Hence, the non-zero capital income tax is the outcome of the effects of medical spending on life expectancy and not because of the effects of medical spending on labour productivity.

Chapter 4

The Effects of Pension Reform on Health Care Spending: An Application to the UK

4.1 Introduction

During the last decades virtually all developed countries have experienced a fast increase in health care and social security spending. Between 1990 and 2009, overall health care spending increased by 38.2% as a percentage of GDP in OECD countries (OECD, 2014), while the share of public expenditure on pensions increased by 27% for the same group of countries over the same period (OECD, 2013*b*) . These trends are likely to continue into the future as there is no reason to expect a slow down in medical improvements and productivity which affect health care expenditure and longevity, adding pressure to the sustainability of social provisions (Whitehouse, 2007). However, simple ad hoc projections of demographics, pensions and health care spending ignore the complex interactions between these social provisions.

Health is a form of human capital which affects productivity, longevity, working hours lost due to illness and welfare directly, while pensions affect medical spending decisions (Zhao, 2014), jointly determining the sustainability of social security provisions. In particular, households derive utility from health care expenditure both directly, enjoying better quality of life (Hall and Jones, 2007) and indirectly through increased longevity (Cutler and McClellan, 2001) which affects the number of periods agents can derive utility from. In addition, the level of health has a positive effect on productivity (presenteism) (Burton et al., 1999), working hours (absenteism) (Grossman, 1972) and affects the probability of early retirement caused by illness.

In a pay-as-you-go social security scheme, increased longevity worsens dependency ratios and governments face the challenge of keeping social security provisions in a sustainable path. As the ratio of retired agents, who receive pensions and are more likely to have higher medical spending (Zweifel, Felder and Meiers, 1999), increases relative to the working population, governments consider structural reforms, such as increasing the retirement age (see Diamond (1996)) and changing the dynamics of inter-generational transfers, increasing taxation and decreasing health care spending and pensions . On the other hand, increased longevity does not necessarily imply that the population is fit to work in older ages, which could partly offset the effects of retirement age reform and potentially increase the need for further health care spending. Hence, taking into account these dynamics one cannot but wonder what is the optimal path of health care expenditure and social security provisions.

This paper is motivated by this question and proposes a general equilibrium overlapping generations model where health care expenditure, economic growth, the age composition and the social security burden are endogenous. We build on the work of Hall and Jones (2007) and Zhao (2014) who investigate the driving forces of health care expenditure growth, but we extend the framework by endogenising economic growth and introducing sick time and congestion in the health care market, which allows us to study the effects of increased longevity on government provisions in a more realistic environment. In contrast to the literature, we study the effect of health care spending and subsequently the level of health on presenteism and absenteism, namely lost productivity and working hours respectively, issues that are particularly relevant when studying the effects of an increase in retirement age, when agents are most likely to be affected by low levels of health. In addition, we also account for health congestion effects on the provision of health care infrastructure since congestion acts as a hindrance on the effectiveness of health care infrastructure with an increasing and ageing population demanding more services. Thus, we can study the general equilibrium effects of factors that are considered by the literature as important determinants of health care expenditure and government policies with respect to taxation, health care and pensions and in turn assess the macroeconomic impact of health as a human capital on output, longevity and government finances and the interaction between health care expenditure and pensions.

Our research is related with the general equilibrium literature on social security, health care and pension spending. In their seminal work, Auerbach and Kotlikoff (1987) provide a general equilibrium, overlapping generations framework to analyze the effects of fiscal policies on growth and welfare. Subsequent studies extend this framework and analyze the path of health care expenditure under different demographic and technological developments in the US (Attanasio, Kitao and Violante, 2010) and the interaction between longevity, human capital accumulation(Ehrlich and Lui, 1991; de la Croix and Licandro, 1999) and retirement (Echevarría, 2004). However, in these models, health care expenditure and longevity are exogenous and cannot explain the determinants of increasing health care expenditure, life expectancy and the interactions with social security. Fonseca et al. (2009), making use of the modeling approach of Hall and Jones (2007) endogeneizes health care spending and longevity and estimates the impact of technological progress, health insurance and income on health care expenditure. In the same spirit, Zhao (2014) studies the effects of social security on Medicare. In particular, these results suggest that an increase in social security benefits, increases the expected value of future utility and agents are willing to spend more on health care in order to increase the probability of survival and take advantage of increased consumption in old age. According to these results, the generosity of social security can explain the residual of increased health care spending over the last decades, after taking into account the effects of income growth and health insurance.

However, to the best of our knowledge the literature has not focused on the effects of the retirement age reform on health care spending, taking into account working hours lost due to illness, productivity and longevity explicitly. In this paper, we fill this gap in the literature, by proposing a general equilibrium model based on the UK economy which allows to examine the effects of an increase of the retirement age on health care expenditure, longevity, dependency ratios and output. We endogeneize health care expenditure and longevity as in Hall and Jones (2007), and incorporate a system of social security scheme as in Zhao (2014), but we also extend the model by endogeneizing working hours lost due to illness and productivity. These additions are qualitatively and quantitatively important, since working hours lost due to illness rise fast with age (ONS, 2014) and postponing the retirement age adds to the working population a demographic group that has ceteris paribus a lower level of health. Furthermore, we decompose the effects of technological progress on the level of health of the population, life expectancy and working hours lost due to illness. We postulate that an increase in the efficiency of medical spending with respect to life-threatening conditions, increases life expectancy but does not necessarily reduce working hours lost due to illness and vice versa[1]. Hence, the assumptions regarding the nature of technological progress leads to different paths of dependency ratios via life expectancy improvements and determine the effectiveness of the retirement age reform, taking into account working hours lost due to illness.

Our results are summarized as follows. First, an increase of the retirement age induces

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[1] For example, better cancer treatment can extend significantly the life expectancy of patients, but it does not necessarily imply that patients are fit to work, while better treatment of conditions that affect quality of life or mobility such as hip replacement may reduce working hours lost, but not have a significant effect on life expectancy.

households to increase health care spending both because of income effects and the effects of working hours lost due to illness. Pension payments as a percentage of GDP fall, which result in lower income taxation and higher savings, increasing the output in the economy. This in turn increases health care spending since in our model, health care expenditure has an income elasticity larger than one. In addition, agents have an additional period of life which they optimize with respect to their working hours lost due to illness, creating an incentive for the households to increase medical spending in order to be fit to work, especially considering the natural deterioration of health over time.

Secondly, technological progress that affects the level of health, the probability of survival and working hours lost due to illness has substantially different effects regarding medical spending, life expectancy and output; (i) improvements of the effectiveness of medical spending on the level of health increases health care spending as a percentage of GDP and marginally increase life expectancy, but GDP falls due to higher taxation in order to finance medical spending, (ii) a ceteris paribus increase in the effectiveness of medical spending on life expectancy, marginally increases health care spending as a percentage of GDP and life expectancy and worsens dependency ratios. However GDP marginally increases since agents discount the future less heavily and increase savings. Furthermore, (iii) improvements with respect to working hours lost due to illness have a more significant impact on GDP without affecting significantly health care spending and dependency ratios.

Finally our results suggest that an increase in consumption tax rate has a redistributive effect between generations as the labour income tax falls and partially compensates the working population. Health care spending rises as a percentage of GDP, despite the reduction of disposable income of older agents, who have higher propensity to consume medical services. In addition, an increase in public investment in health care infrastructure and a reduction of the subsidy rate both have a positive effect on output but opposite effects on the level of health care spending. In the former, the increased efficiency of medical spending tends to increase the demand for health care, while for the latter, the increase in price has the opposite effect. These results suggest that the health care subsidy rate and the level of investment in health care infrastructure are not optimal, taking into account the efficiency of medical spending and the effects of health care spending on government finances and output.

Before moving further, a clarifying note on the focus of our analysis on the UK health care system. Firstly, the UK's NHS has served as a model for many countries in continental Europe and hence our model is appropriate for analyzing countries that do not share the same institutional arrangements as in the US with respect to health care insurance and social security in general. Secondly, by focusing in the UK, where health care insurance is mainly publicly provided, free at the point of service and financed by general taxation, we can abstract from complicated insurance schemes without being less realistic and concentrate on aspects that are more relevant for our analysis.

The rest of the paper is organized as follows. In the next section we describe the multi-period, overlapping generations model which constitutes the framework of our analysis. In section three we calibrate the model in order to fit the UK data and in section four we present the simulation results for the scenarios we consider. Finally, we conclude with section five.

4.2 The Model

We build on the work of Auerbach and Kotlikoff (1987), Hall and Jones (2007) and Zhao (2014) and make use of a general equilibrium overlapping generations model. Agents survive at most for J periods, with endogenous probability of survival between age cohorts and they derive utility from consumption and their level of health. They decide their optimal allocation between savings, consumption and private health care expenditure taking into account the subsidies rate provided by the government and earn wages until the retirement period J_R, constrained by the amount of healthy time and receive pensions after period J_R. On the other hand, the government's role is passive, subsidizing a constant fraction of the desired level of health care expenditure by the households, making pension payments that are a fixed fraction of the prevailing wage and investing a constant share of GDP in health care infrastructure. In addition, the government has two sources of revenue, a constant rate of consumption tax for all age cohorts and an labour income tax, which adjusts in order to balance the government budget.

4.2.1 Households

Households can potentially live for up to J periods, providing a maximum of one unit of labour inelastically until the retirement age $J_R < J$ and retiring while receiving pensions after the retirement period J_R. In this model, agents derive utility both from consumption and the level of health as in Hall and Jones (2007). Health is endogenous and can be influenced by medical expenditure and public investment in health care infrastructure. The probability of survival is also endogenous, depending on the level of health as in Zhao (2014) and Feng (2010). Households that do not survive to the next period leave involuntary bequests that are seized by the government and constitute an additional source of government revenue. With this in mind, the life-time utility function can be described as:

$$U = \sum_{j=1}^{J} \beta^{j-1} P_{j,t}\left(h_{j,t}\left(m_{j,t}\right)\right) u_{j,t}\left(c_{j,t}, h_{j,t}\left(m_{j,t}\right)\right) \tag{4.1}$$

with:

$$P_{j,t}\left(h_{j,t}\left(m_{j,t}\right)\right) = \prod_{i=1}^{j-1} p\left(h_{i,t}\left(m_{i,t}\right)\right) p\left(h_{j,t}\left(m_{j,t}\right)\right) \tag{4.2}$$

where j denotes age cohort, $c_{j,t}$, $h_{j,t}\left(m_{j,t}\right)$ and $m_{j,t}$ are consumption, level of health and aggregate medical spending (private and public) in period t for cohort j respectively, β is the discount rate, while $p_{j,t}\left(h_{j,t}\left(m_{j,t}\right)\right)$ denotes the probability of surviving to age cohort j, conditional on surviving until $j-1$ and $P_{j,t}\left(h_{j,t}\left(m_{j,t}\right)\right)$ the unconditional probability of being alive at cohort j. In a nutshell, agents do not only decide the allocation of consumption and medical spending between periods, but also the number of periods they derive utility from, taking into account their survival probabilities when deciding the level of medical spending[2].

The budget constraints of the agents while working ($j < J_R$) are described as:

$$\left(1+\tau_c\right) c_{j,t}+\left(1-q_j\right) m_{j,t}+a_{j,t}=\left(1-\tau_w\right)\left(1-s_{j,t}\left(h_{j,t}\left(m_{j,t}\right)\right)\right) w_t e^{\zeta \bar{h}}+\left(1+r_t\right)\left(a_{j-1,t-1}\right) \tag{4.3}$$

and when retired ($j \geq J_R$):

$$\left(1+\tau_c\right) c_{j,t}+\left(1-q_j\right) m_{j,t}+a_{j,t}=\chi w_t e^{\zeta \bar{h}}+\left(1+r_t\right)\left(a_{j-1,t-1}\right) \tag{4.4}$$

with τ_c denoting the consumption tax, q_j the constant, exogenous level of health care subsidy provided by the government, τ_w the income tax, $s_{j,t}\left(h_{j,t}\left(m_{j,t}\right)\right)$ working hours lost due to illness, a_j savings, r_t the interest rate and χ the pension replacement rate. Hence, working agents provide less than one unit of labour, with the rest being working hours lost due to illness, which in turn is conditional on the level of health (absenteeism). In addition, health is productivity-enhancing by a factor $e^{\zeta \bar{h}}$, where ζ is a scaling parameter and $\bar{h}$ the average level of health of the working population, as in Bloom and Canning (2005), with low levels of health resulting in lower productivity

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[2] There are mixed results regarding the marginal effect of medical spending on survival probability, a phenomenon referred as "flat of the curve" medical spending. However, recent empirical evidence suggest that there is a positive and significant effect of medical spending on mortality (Card, Dobkin and Maestas, 2009)

(presenteism).

In our model, the population of young agents grows at a constant rate n and they bear children at the end of the first period of life, before the mortality rate is realized[3]. Since the probability of survival is less than one, the size of each cohort j at time t is denoted as:

$$\mu_{j,t} = \frac{p(h_{j-1,t-1})}{1+n}\mu_{j-1,t-1} \tag{4.5}$$

with the sum of all cohort measures in the first period being 1 for normalization:

$$\sum_{j=1}^{J} \mu_{j,1} = 1 \tag{4.6}$$

The level of health of each household is described as in Zhao (2014), with the new element being the inclusion of congestion effects:

$$h_{j,t} = h_{j-1,t-1}\left(1-\delta_j\right) + Q_j m_{j,t}^{z_j}\left(\frac{\xi Y_t}{M_t}\right)^{\phi} \tag{4.7}$$

where δ_j is the rate of health depreciation, $m_{j,t}$[4] are aggregate-private and public- medical expenditures, z_j captures the elasticity of medical expenditure with respect to the level of health, Q_j is a scale parameter that determines the effectiveness of health care expenditure with respect to health. We contribute to the literature by incorporating the effects of congestion and an additional term that affects the effectiveness of health

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[3] We abstract from the effect of mortality of young agents on fertility, as agents bear children before the mortality probability is realized. Considering that the first age cohort consists of agents until their late 20's, we consider it a reasonable approximation.

[4] It should be noted that m_i, aggregate health care expenditures are a choice variable for the agents, however a fraction $(1-q_j)$ is subsidized by the government, which is exogenous and constant, calibrated to the UK data. In essence, $q_j m_j$ is the private share of health care expenditure and $(1-q_j)m_j$ is the share subsidized by the government. In addition to subsidizing health care expenditure, the government invests in health care infrastructure, equal to a constant fraction of GDP ξ, which enhances the productivity of medical spending, such as hospitals, medical equipment etc.

care spending, $\left(\frac{\xi Y_t}{M_t}\right)^{\phi}$. In the model, government investment in health care infrastructure is described as ξY_t, with Y_t the level of economic output and ξ the fraction devoted to health care investment, while ϕ captures the intensity of congestion effects on health. In addition, M_t is the overall medical expenditure, for all cohorts at period t, and is the variable that introduces congestion. An increase in demand for medical expenditure or a greater population will increase total medical expenditure, lowering in turn the effectiveness of health care spending for a given level of infrastructure. In essence, households start with a level of health which depreciates over time with an increasing rate δ_j[5] and through medical spending households can increase their stock of health in the spirit of Grossman (1972), constrained by congestion effects as described above.

In addition, as in Feng (2010) we assume the following function for the probability of survival:

$$p_j\left(h_{j,t}\right) = 1 - e^{-\left(a_p h_{j,t}\right)^{b_p}} \tag{4.8}$$

with a_p determining the scale effect of health on survival probability and b_p the elasticity of the probability of survival with respect to the level of health. We use a similar function to describe the percentage of maximum hours agents can provide in the labour market, taking into account hours lost due to illness is described as:

$$1 - s_j\left(h_{j,t}\right) = 1 - e^{-\left(a_s h_{j,t}\right)^{b_s}} \tag{4.9}$$

where again a_s determines the scale effect of health on working hours and b_s the curvature of the function.

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[5] It is a well known peculiarity of health as a stock that a constant depreciation rate implies that depreciation is higher when the stock of health is high. It is standard in the literature (see for example Hall and Jones (2007) and Zhao (2014)) to adopt age specific depreciation rates in order to overcome the issue of faster deterioration of health in younger ages compared to older ones.

Both the probability of survival and working hours are described by the same Weibull cumulative distribution with different parametric specification in order to fit the UK data. Although the use of the same functional form is arbitrary, a major advantage is that it constrains the probability of survival and the fraction of worked hours within the $(0, 1)$ interval. In addition, any function that is a probability function and is concave with respect to the level of health can be calibrated to match the UK data and provide a reasonable approximation.

4.2.2 Firms

There are two sectors in the economy, the medical sector and the sector that produces the rest of goods and services . We assume perfect mobility of capital and labour and that both sectors share the same production function, as in Zhao (2014)[6]. Thus the economy collapses in a one sector economy. The production function is the following:

$$Y_t = F(K_t, A_t\tilde{L}_t) = A_t K_t^{\alpha} \tilde{L}_t^{1-\alpha} \tag{4.10}$$

where capital is the sum of all agents' savings:

$$K_{t+1} = \sum_{j=1}^{J-1} \mu_{j,t} a_{j,t} \tag{4.11}$$

and effective labour supply is the sum of the labour supply of all working age agents, taking into account productivity and working hours lost due to illness:

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[6] The assumption that the private health care sector, which for simplification is the only provider of health care in our economy, shares the same productivity as the rest of the economy is a strong one. Relaxing this assumption results in price differentials that affect the allocation of spending between consumption and health care (Hartwig, 2008) with interesting implication. Given, however, that the analysis of such allocations are not the main objective of this study, we let this exercise for future research.

$$\tilde{L}_t = \sum_{j=1}^{J_R-1} \mu_{j,t} e^{\zeta \bar{h}} \left(1 - s_{j,t}\left(h_{j,t}\left(m_{j,t}\right)\right)\right) \tag{4.12}$$

Finally, capital and effective labour are compensated for their marginal product since markets are perfectly competitive and clear. Hence, the real wage and the rate of return to capital are determined as:

$$w_t = (1-\alpha) A_t \left(\frac{K_t}{\tilde{L}_t}\right)^{\alpha} \tag{4.13}$$

$$r_t = \alpha A_t \left(\frac{K_t}{\tilde{L}_t}\right)^{\alpha-1} - 1 \tag{4.14}$$

where we assume that the depreciation rate of capital in the economy is equal to one.

4.2.3 Government

The last agent in our economy is the government, which runs a balanced budget every period. It taxes labour income and consumption and provides subsidised health care services, health care infrastructure and pensions for the old, while spends a constant fraction of output on general government consumption.

$$\begin{aligned} &\tau_w w_t e^{\zeta \bar{h}} \sum_{j=1}^{J_R-1} \mu_{j,t}\left(1 - s_{j,t}\left(h_{j,t}\left(m_{j,t}\right)\right)\right) + \tau_c \sum_{j=1}^{J} \mu_{j,t} c_{j,t} + beq_t = \\ &= \sum_{j=1}^{J} \mu_{j,t} q_{j,t} m_{j,t} + e^{\zeta \bar{h}} \chi w_t \sum_{j=J_R}^{J} \mu_{j,t} + gY_t + \xi Y_t \end{aligned} \tag{4.15}$$

where

$$beq_t = \sum_{j=1}^{J} (1 - \mathrm{P}_{\mathrm{j-1,t}}) a_{j,t} \tag{4.16}$$

denote bequests of deceased agents that are seized by the government.

For simplicity and since it is a good approximation of the actual UK government policy, we assume that the government keeps q_j constant, that is the fraction of aggregate health care expenditures payed by the agents. Historically the private share of health care expenditure hovers around 20% of the aggregate health care expenditures(ONS, 2013*a*). This means that the agents make decisions regarding their health care expenditure in order to maximize their utility taking q_j as given, which in turn means that the government covers a fraction $(1 - q_j)$[7]. For the benchmark case, the consumption tax τ_c, χ, the fraction of the wage that is payed as pensions, g the fraction of GDP that is devoted to general government consumption and ξ the fraction of GDP that are devoted to health care investment remain constant. Hence the instrument that the government controls in the benchmark case in order to balance the budget is the tax rate τ_w.

Hence, the resource constraint of the economy is given by:

$$C_t + M_t + K_{t+1} + \xi Y + G \leq Y_t = F(K_t, A_t \tilde{L}_t) \tag{4.17}$$

with

$$C_t = \sum_{j=1}^{J} \mu_{j,t} c_{j,t} \tag{4.18}$$

$$M_t = \sum_{j=1}^{J} \mu_{j,t} m_{j,t} \tag{4.19}$$

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[7] In our model, q_j is treated as exogenous since we focus on the agent's problem. The analysis of the government's optimal level of subsidy is left for future research.

4.2.4 Decentralized Equilibrium

The individual agent's problem is to maximize her lifetime utility function (1) subject to the budget constraints (4.3) and (4.4), $c_j > 0$, $m_j > 0$ given factor prices w_t, and r_t and fiscal variables q_j, τ_c τ_w, ξ and χ[8]. The following definition may be proposed:

Definition: A competitive equilibrium for this economy is a sequence of allocations $\{c_{j,t}\}_{t=1}^{\infty}$, $\{m_{j,t}\}_{t=1}^{\infty}$ and $\{h_{j,t}\}_{t=1}^{\infty}$, given sequences of prices $\{r_t\}_{t=1}^{\infty}$ and $\{w_t\}_{t=1}^{\infty}$, $\{\tau_{c,t}\}_0^{\infty}$, $\{\tau_{w,t}\}_0^{\infty}$, $\{\chi_t\}_0^{\infty}$,$\{\xi_t\}_0^{\infty}$ and $\{q_t\}_0^{\infty}$such that the individual maximizes life-time utility, firms maximize profits, the government budget is balanced and markets clear.

4.3 Calibration and Steady State Results

Unfortunately, the complexity of the model does not allow for a closed form solution, instead we rely on numerical simulations to obtain our results[9]. Here, we present the calibrated benchmark model which is used to assess the quantitative impact of effects of i) increases in retirement age, ii) technological progress in the medical sector, iii) aggregate productivity growth, and iv) government policy instruments. Whenever possible we use parameter values based on the existing literature, however some parameter values, such as the health production function and probability of survival, are model specific and are determined simultaneously in order to fit the UK data in 2015 or the latest available data.

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[8] The formal problem can be found in the Appendix

[9] We were able to obtain a closed form solution when the probability of survival is exogenous. Although the analytical solution provides intuition about key macroeconomic variables in our model following a marginal, exogenous change in the probability of survival, the importance of the latter in our model lead us to demonstrate the results of the numerical simulations.

4.3.1 Demographics

The maximum number of periods agents can survive is set to $J = 8$, with each period in the model corresponding to 10 years. Agents enter the economy at the age of 20 and they survive maximum at the age of 100. The retirement age in the benchmark model is set to $J_R = 5$, which means that agents retire at the age of 60. The yearly population growth is set to $n = 0.62\%$ (ONS, 2013*b*), consistent with the UK data.

4.3.2 Preferences

The instantaneous utility of the agent of cohort j at time t is determined by the utility function as proposed by Hall and Jones (2007):

$$u_{j,t} = b + \frac{c_{j,t}^{1-\gamma}}{1-\gamma} + \psi \left[\frac{h_{j,t}\left(m_{j,t}\right)}{1-\sigma} \right]^{1-\sigma} \tag{4.1}$$

where b is a constant parameter, ψ is the relative weight of health in the utility function and γ and σ are the coefficients of relative risk aversion of consumption and health respectively. We calibrate the parameters, presented in Table 4.1, drawing directly from the estimated parameter values of Hall and Jones (2007), setting $b = 66.27$, $\gamma = 2$, $\sigma = 1.051$, and $\psi = 2.396$. In the life-time maximization problem we set the agent's discount rate β to $0.75 \approx 0.97^{10}$ as in Zhao (2014).

The functional form of the utility function plays a non-trivial role in our model. As Hall and Jones (2007) show, this specification allows increasing health care expenditure as a percentage of GDP with increasing income, resulting in an income elasticity of health care expenditure higher than one[10]. Although empirical studies with different

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[10] As Rossen (1988) points out, in contrast to the standard models with exogenous probability of survival, where only marginal utility is relevant for optimal decisions, when the probability of survival is endogenous the level of utility is significant as well. In a nutshell, agents do not only decide the allocation of consumption between periods, but also the number

specifications and samples provided mixed results with respect to the income elasticity of health care (for a comprehensive review see Gerdtham and Jönsson (2000)), Getzen (2000) notes that health care is both a necessity and a luxury good depending on the level of the analysis. In particular, insured individuals have an income elasticity close to zero, while on a country level. the income elasticity is larger than one, which is the specification we adopt in this model.

Hence, an exogenous increase in total factor productivity (TFP) will result in higher health care expenditure as a percentage of GDP and subsequently higher life expectancy, even in the absence of technological progress or changes in government policy. Importantly, taking into account the income elasticity of health care expenditure, we can analyze the indirect impact of government policies, such as the retirement age reform, on health care expenditure through the level of output.

4.3.3 Health, Probability of Survival and Working Hours Lost

The health production function as discussed previously is expressed as in (4.7):

$$h_{j,t} = h_{j-1,t-1}\left(1-\delta_j\right) + Q_j m_{j,t}^{z_j}\left(\frac{\xi Y_t}{M_t}\right)^{\phi}$$

The values of δ_j, Q_j and z_j, are age and model specific (Table 4.1). We assume that the values of δ_j and z_j increase with age, while Q_j decreases in order to reflect the deterioration of health as agents age and the reduced effectiveness of medical spending

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of periods they derive utility from. However, as Hall and Jones (2007) note, in the stardard CRRA utility functions the level of utility is negative for standard values of the coefficient of relative risk aversion. In order to overcome this issue, where it is optimal for the agent to choose less periods of consumption since the sum of per period utility is negative, they add a constant parameter. The intuition of the constant parameter, is simple; the utility that the agent derives simply by being alive, ignoring consumption and the level of health. As Hall and Jones show, the introduction of b is sufficient to generate increasing share of health care expenditure as income rises on the elderly compared to younger agents[11]. The fraction of GDP devoted to public health care infrastructure is set to $\xi = 1\%$ of GDP, while ϕ which captures the intensity of the congestion effect has been set to one for simplicity[12].

The parameter values of a_p, b_p and a_s, b_s of the survival probability function and working hours respectively are also described in Table 4.1. With the given health level of each cohort, we calibrate the parameter values in order to fit the UK data with respect to the survival probability and working hours lost.

4.3.4 Production Technology

The share of capital in our economy is set to $\alpha = 0.3$ (Attanasio, Kitao and Violante, 2010). The productivity enhancing parameter ζ in $e^{\zeta \bar{h}}$ is set to 0.005 to match the household's health care spending profiles. Total factor productivity is set as $A = 1$ for normalization and we study the effect of an increase in productivity in subsequent sections, assessing the impact of TFP on health care expenditure, longevity and the level of health.

4.3.5 Social Security and Government Spending

We assume that the government adjust the income tax rate τ_w, in order to balance its budget. In our model, τ_w captures both income tax and social insurance contributions, which is the most relevant tax rate for studying the effects of health care and pension spending. The consumption tax rate, τ_c is set to 20% to match the UK VAT rate, $\chi = 0.326$, which is the average pension replacement rate in the UK OECD (2013*b*), and $g = 0.15$ to match the level of overall government spending as a percentage of

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[11] Since in our model, the level of medical spending is normalized, it takes values less than one. Thus, a decrease in z_j would result in higher efficiency.

[12] Changing the value of ϕ affects the quantitative results of the model such as the level of health care expenditure, health and life expectancy, but not the qualitative results.

GDP. The fraction of out-of-pocket payments is set to $q_j = q = 0.2$, which in turns suggests that the level of government subsidies of health care expenditure is 80%, close to the historical average of the UK economy ONS (2013*a*).

Table 4.1: Parameters

Paramameter	Value	Explanation
b	66.27	Constant in $U(c,h)$
γ	2	Coefficient of relative risk aversion (consumption)
A	1	Total Factor Productivity
σ	1.051	Coefficient of relative risk aversion (health)
ψ	2.396	Relative weight of health in the utility function (young)
β	0.75	Discount rate
δ	{0.1,0.2,0.3,0.4,.05,0.6,0.7,0.8}	Health depreciation rate (age-specific)
a	0.3	Capital share in the production function
q	0.15	Private share of medical expenditure
Q	5	Scale parameter of the health production function
z	{0.1,0.2,0.3,0.4,.05,0.6,0.7,0.8}	Curvature parameter of the health production function
a_p	{10,8,6,3,2.5,2,0.5,0}	Scale parameter of the probability of survival
b_p	0.5	Curvature parameter of the probability of survival
a_s	{2,2,2.5,3,3.8}	Scale parameter of healthy time
b_s	0.5	Curvature parameter of healthy time
τ_c	0.2	Consumption tax rate
ξ	0.01	Public investment in health care infrastructure
χ	0.326	Pension replacement rate
ϕ	1	Curvature parameter in congestion

4.3.6 Calibration Results

The model fits the data reasonably well both with respect to the levels of aggregate variables (Table 4.2) and the age profiles (Figures 4.1-4.2). According to our simulation results, aggregate health care expenditure, pensions as a percentage of GDP, life expectancy, sick time, the dependence ration and the income tax rate are close to the actual data.

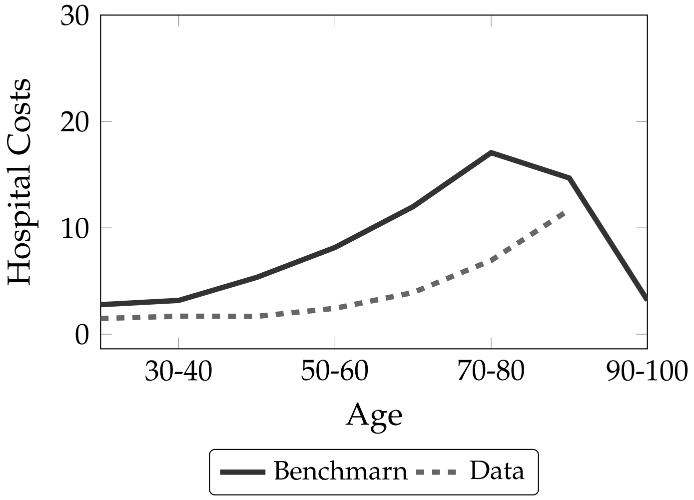
TABLE 4.2: STEADY STATE RESULTS

	Data	Benchmark
Health Care Expenditure, % GDP	8.8	8.1
Pensions, % GDP	7.1	7.68
NHS, % GDP	6.2	5.68
Dep. Ratio	54	48.32
Sick Time, %	2.1	1.8
Life Expectancy At 20	59.6	60.79
Life Expectancy At 60	22.4	21.05
Income Tax, %	31.1	31.35
Savings, % GDP	13	23.31

Notes: Data are collected from stat.OECD, Labour Force Survey (2013) and Human Mortality Database (2014)

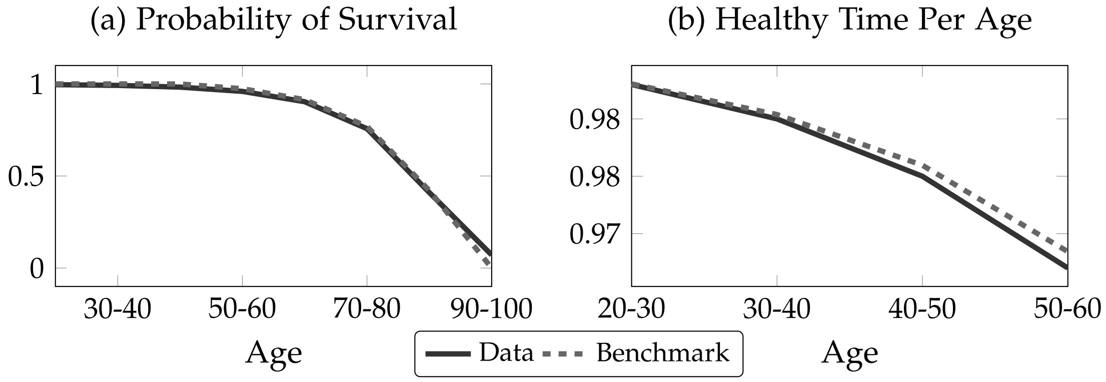
With respect to the decomposition of aggregate private health care expenditure per age cohort, the model fits the trend of the increasing health care expenditure, albeit with a margin of error with respect to the magnitude (Figure 4.1). Health care expenditure are increasing with age, as agents are willing to spend an increasing share of their income in order to compensate for the health deterioration and reduced probability of survival. During the last period of life, agents leave the economy with certainty and thus medical spending is reduced sharply in our model, when agents invest in health only as a quality of life parameter. With respect to savings, the model is expected to underestimate the level savings since the agents face no precautionary motive caused by labour income earnings uncertainty.

Figure 4.1: Per Capita Health Care Expenditure as a % of Per Capita GDP



Notes: Data are obtained from Kelly, Stoye and Vera-Hernández (2015)

Figure 4.2: Probability of Survival and Healthy Time per Age



Notes: Data are obtained from Human Mortality Database (2014) and (ONS, 2014) respectively. Healthy time refers to the percentage of potential hours of work not lost due to illness

4.4 Policy Experiments

As a first experiment, we perform simulations in order to analyze the effect of the retirement age reform, postponing the retirement age from 60 to 70 years of age, on (i) health care expenditure, (ii) longevity, (iii) dependency ratios, (iv) output, (v) sick time, (vi) the income tax rate and (vii) savings in the UK by 2046, when the retirement reform will have been fully implemented. We focus on these variables, since they are the main source of concern regarding the sustainability of social provisions and the implementation of the retirement age reform explicitly targets dependency ratios. Recent literature has focused on the effects of an exogenous increase in retirement age on savings and growth (Echevarría and Iza, 2006), the relation between early retirement decisions and the level of health (Ferreira and dos Santos, 2013), the optimal choice of health care expenditure taking into account the generosity of pensions (Zhao, 2014) and the relation between health and the disutility from working (Kuhn et al., 2015). To the best of our knowledge, we are the first to focus on the interactions between health care expenditure and working hours lost due to illness in a general equilibrium model.

In a second exercise, we take into account factors that affect health care spending and hence longevity and dependency ratios, in particular income and technological progress in the medical sector. Both income and technological progress in the medical sector are widely researched in the literature[13] with respect to health care expenditure, however our focus is different. In our model, the income elasticity of health care is central because of the utility function as described in Hall and Jones (2007) that relates the effects of the retirement age reform on health care expenditure through the level of output. Furthermore, instead of focusing on the the relative productivity of the health care sector and the price differential between general consumption and

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[13] See for example Newhouse (1977); Parkin (1987); Hall and Jones (2007) and Okunade and Murthy (2002); Fonseca and Galama (2013) respectively

medical services (Hartwig, 2008), we decompose the effects of technological progress on the key variables in our model, the level of health, probability of survival and sick time. The distinction between these effects is important for our simulations, since they determine the path of dependency ratios, life expectancy and working hours lost due to illness.

Finally, we consider the effects of government policies as a response to increasing health care and pension expenditure and deteriorating dependency ratios. In a nutshell, we consider changes in the government's instruments such as (i) consumption tax, (ii) pension replacement rate, (iii) investment in health care infrastructure and (iv) the level of health care subsidy. We then compare their effects with the retirement age reform with respect to health care spending, taxation, longevity, output, sick time and savings. With the recent demographic developments that apply pressure on social provisions, the recent literature has focuses on fiscal policies with respect to the consumption tax rate and pension replacement rates (Nishiyama, 2015; El Mekkaoui de Freitas and Oliveira Martins, 2014; Heer and Irmen, 2014) and our model serves as a useful extension taking into account health explicitly. On the other hand, public investment in health care infrastructure has been studied mainly in a developing framework (Agénor and Neanidis, 2006) and the notion of congestion is put forward as a hindrance in poorer countries with lower levels of public infrastructure (Agénor, 2008). However, evidence for the case of the UK (Besley, Hall and Preston, 1999, 1998) suggest that waiting times are a significant factor with respect to health care productivity and the future demographic developments will tend to amplify the importance of infrastructure. Finally, due the the recent structural reform of the health insurance in the US, the literature has focused and the effects of the coinsurance rate on health care expenditure and government finances (Feng, 2010), however little attention has been payed to the case of the National Health System in the UK.

4.4.1 Retirement Age Reform

In order to assess the impact of retirement age reform we perform the following exercise. We simulate the effect of the full implementation of retirement age reform on the benchmark model, calibrated for 2015 and then simulate the economy in 2046 with and without the retirement age reform, taking into account TFP growth and technological progress in the medical sector. We assume that A, the TFP, increases by 1% annually, while the rate of health depreciation δ_j decreases by 1% annually and Q_j, a_{p_j} and a_{s_j}, the scale parameters in the health production function, probability of survival and working hours respectively increase by 1% per year[14]. Hence, we can decompose the effects of income, technological progress and retirement age reform from the overall change in health care expenditure, longevity and output.

Retirement age reform has the expected impact on pensions spending and dependency ratios, reducing pension payments as a percentage of GDP and improving dependency ratios, however health care spending increases both in 2015 and 2046. By 2046, pension reform has modest effects on pensions spending as a percentage of GDP compared to the same reform in the benchmark model. A full implementation of the retirement age reform today results in a significant reduction on pension payments as a percentage of GDP, however until 2046 the effect is more modest, even though pensions are lower than the benchmark. Our simulation results suggest that the government's plan of increasing the retirement age incrementally until 2046 is sufficient to keep pension payments relatively stable as a percentage of GDP. However, the dependency ratio rises significantly and is not improved to the same level as after the retirement reform

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[14] According to Pessoa and Reenen (2012), the average TFP growth during the period 1979-2007 was 1% in the UK. For the rest of the parameters, since they are model specific, we make the assumption that the annual improvement is 1% in order to match the increase in productivity for the rest of the economy. As our results suggest, the increase in life expectancy is in line with the recent literature (Bennett et al., 2015) (6.5 years until 2046 as opposed to 6.2 years until 2030), which makes the 1% increase in the efficiency of the medical sector a good approximation for our parameters.

Table 4.1: Retirement Reform

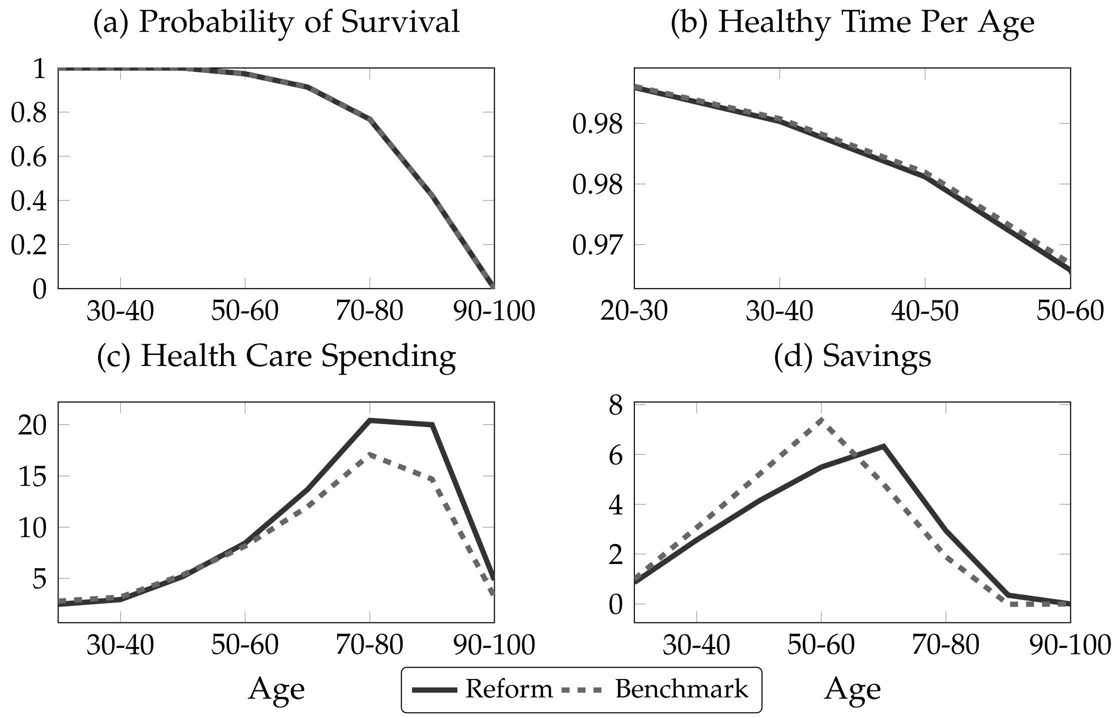
	2015		Projection 2046	
	Benchmark	Reform	No Reform	Reform
Health Care Expenditure, % GDP	8.1	8.92	13.31	14.43
Pensions, % GDP	7.68	3.91	8.66	7.47
NHS, % GDP	5.68	6.33	10.65	11.54
Dep. Ratio	48.32	23.43	57.52	30.68
Sick Time, %	1.8	2.55	0.62	0.69
Life Expectancy At 20	60.79	60.75	67.5	67.51
Life Expectancy At 60	21.05	21.02	27.54	27.56
GDP Change, %	0	12.71	66.36	92.06
Income Tax, %	31.35	23.19	44.88	37.56
Savings, % GDP	23.31	22.67	23.75	23.53

Notes: We perform four simulations; two in 2015 comparing the benchmark case and a full immediate implementation of the retirement age reform and two in 2046, taking into account TFP growth and technological progress in the medical sector, with and without the implementation of the retirement age reform.

in 2015.

More importantly, the retirement age reform causes a significant rise in health care spending (8%). Households have an incentive to increase health care spending since they face a higher retirement age. Raising the retirement age from 60 to 70 and taking into account the fast rate of health depreciation at older ages, induces households to increase their medical spending in order to reduce working hours lost due to illness. However, retirement age reform has an additional effect on health care spending through higher income. Reducing the dependency ratio and hence the income tax rate in order to finance pensions, results in higher level of savings and subsequently output. In our model, medical spending is a luxury good and increasing income results in higher health care expenditure as a percentage of GDP. In order to demonstrate the effect, we have simulated a change in retirement age with working hours lost due to illness not being a choice variable (Table 4.2) during the last working period of their lives. In this counter factual exercise, agents choose the level of medical spending taking into account working hours lost due to illness for the first four periods of their lives, but not the additional period after the retirement age reform. Indeed, even if households do not choose the amount of hours lost due to illness, health care spending still increases.

FIGURE 4.1: RESPONSE OF INDIVIDUAL VARIABLES AFTER A CHANGE IN THE PENSION REPLACEMENT RATE



Notes: We assume that the retirement age increase from 60 to 70 years old.

Hence, our results suggest that although an increase in retirement age has a positive effect in dependency ratios, productivity and working hours lost due to illness, health care expenditure increase as a percentage of GDP, offsetting the positive effects of reduced taxation and government spending. Incorporating working hours lost due to illness and an income elasticity of health care expenditure larger than one in a model that studies the effects of the retirement age reform, underlines the bi-directional relation between health care expenditure and pension reform.

TABLE 4.2: COUNTER-FACTUAL SIMULATION

	Benchmark	Reform	Counter Factual
Health Care Expenditure, % GDP	8.1	8.92	8.87
Pensions, % GDP	7.68	3.91	3.92
NHS, % GDP	5.68	6.33	6.29
Dep. Ratio	48.32	23.43	23.44
Sick Time, %	1.8	2.55	2.54
Life Expectancy At 20	60.79	60.75	60.76
Life Expectancy At 60	21.05	21.02	21.03
GDP Change, %	0	12.71	12.75
Income Tax, %	31.35	23.19	23.12
Savings, % GDP	23.31	22.67	22.68

Notes: We compare the results between the benchmark case, the retirement age reform and the counter-factual where households do not take into account working hours lost due to illness during the additional period, after the retirement age reform.

4.4.2 Comparative Statics

The projection for the UK economy in 2046, takes into account both the projected TFP productivity growth and improvements in medical technology. As discussed previously, since health care spending is a luxury good, an increase in TFP and hence GDP results in higher medical spending, a result consistent with the literature that makes use of this class of utility functions. Therefore, improvements in TFP result in a higher level of health and subsequently longevity and dependency ratios. Between the benchmark case in 2015 and 2046, a fraction of health care spending increase results from a higher TFP, in particular solely because of TFP growth health care spending increases by 2.1 percentage points. The rest of the increase in health care spending is distributed between changes in four parameters related to health, δ_j, Q_j a_{p_j} and a_{s_j}, the rate of health depreciation, the effectiveness of medical spending with respect to health, the effectiveness of health on survival probability and the effectiveness of health on working hours lost due to illness respectively. In order to assess the impact of each individual parameter on the evolution of health care spending, we have

TABLE 4.3: CETERIS PARIBUS SIMULATION

	Benchmark	Q	δ	a_p	a_s	TFP	Full Scenario
Health Care Exp., % GDP	8.1	14.96	8.02	8.11	8.11	10.17	13.31
Pensions, % GDP	7.68	7.92	7.71	8.15	7.62	7.7	8.66
NHS, % GDP	5.68	11.16	5.62	5.69	5.69	7.34	10.65
Dep. Ratio	48.32	49.65	48.63	51.26	48.32	48.17	30.68
Sick Time, %	1.8	1.81	1.77	1.81	0.95	1.86	0.62
Life Expectancy At 20	60.79	62.32	61.01	62.41	60.79	60.77	67.5
Life Expectancy At 60	21.05	22.58	21.26	22.54	21.05	21.04	27.54
GDP Change, %	0	-0.5	0.3	0.65	0.92	54.76	66.36
Income Tax, %	31.35	41.5	31.36	32.86	31.22	34.28	44.88
Savings, % GDP	23.31	23.21	23.35	23.62	23.34	23.12	23.75

Notes: All parameters increase by a factor of $(1.01)^{30}$, hence 1% per year until 2046, with the exception of δ_j that is reduced by the same amount. In the Full scenario we simulate the changes in the parameters simultaneously.

simulated the change to 2046 independently for each parameter, keeping the rest constant.

We distinguish between the four parameters related to health in order to reflect the different technological and institutional effects on the level of health, longevity and working hours lost due to illness. In a nutshell, improvements with respect to δ_j that are considered unrelated with medical spending but reduce the rate of health depreciation[15]. Changes in the parameter Q_j, relate to changes in the effectiveness of medical spending on the health level directly, while a_{p_j} reflects changes that affect the effectiveness of medical spending and health on the probability of survival, such as improvements in cancer treatment, cardiovascular diseases and so on. Finally, changes in a_{s_j} reflect improvements in medical technology that reduce the amount of working hours lost due to illness and do not relate to the probability of survival, such as more effective treatment that reduces days spent in hospital or better treatment for non

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[15] For example, government policy such as pollution regulation or government infrastructure such as sewerage are not considered health care spending but significantly influence the level of health of the population.

life-threatening conditions such as hip replacement or mental health.

This distinction between the parameters related to health is quantitatively and qualitatively important because the effect of each parameter on health care expenditure, life expectancy, income tax and the level of output is different both in magnitude and sign. Improvements on the level of health that are unrelated with medical expenditure (δ) result in lower health care spending since, ceteris paribus agents have a higher level of health, but the increase in survival probability reduces the dependency ratio . However, the aggregate effect is positive, as agents are more productive and lose less working hours due to illness, resulting in higher output. A direct improvement of a_p has a positive effect on health care spending and obviously the probability of survival, as life expectancy at 60 increases and deteriorates the dependency ratio. The impact of such improvements on aggregate output is marginally positive, despite the rise in both health care expenditure and pensions, since agents discount the future less heavily and increase savings. Finally, an increase in the effectiveness of health on healthy time, marginally increases health care spending and reduces pensions, however less working lost due to illness contribute to higher output and lower income tax in order to finance government expenditure.

The comparative statics exercise demonstrates more transparently the effects of technological progress and income growth on health care expenditure, dependency ratios and output. This is necessary for a sustainable social security system, since as our results suggest, raising the retirement age to 70 until 2046 may not be enough to curb the rising dependency ratios, depending on the assumptions of technological progress and TFP growth. Technological progress that increases life expectancy without significant effects on the level of health and working hours can result to an aging population that is unfit to work. On the contrary, technological progress that increases the level of health decreases health care spending and increases working hours offsetting the effects of increased life expectancy on dependency ratios and pensions.

Table 4.4: Policy Experiments

	Benchmark	τ_c	χ	ξ	q
Health Care Expenditure, % GDP	8.1	8.15	6.94	11.89	7.02
Pensions, % GDP	7.68	7.68	7.07	7.74	7.68
NHS, % GDP	5.68	5.72	5.55	7.92	5.59
Dep. Ratio	48.32	48.31	48.36	49.28	48.33
Sick Time, %	1.8	1.8	1.79	1.66	1.8
Life Expectancy At 20	60.79	60.78	60.8	61.44	60.8
Life Expectancy At 60	21.05	21.04	21.06	21.67	21.06
GDP Change, %	0	0.52	1.12	0.39	0.07
Income Tax, %	31.35	27.7	29.92	37.53	31.2
Savings, % GDP	23.31	23.55	23.8	22.9	23.33

Notes: We assume that τ_c increases from 20% to 25%, χ from 32.6% to 30%, ξ from 1% to 2% and q from 20% to 19%.

4.4.3 Government Instruments

In the model there are five government instruments, the labour income tax rate τ_w, consumption tax rate τ_c, the pension replacement rate χ, the level of health care spending subsidy q and the percentage of GDP devoted to health care infrastructure ξ. In the benchmark model, the first instrument adjusts in equilibrium in order to balance the government budget, hence we perform simulation of changes in the government policy with respect to the rest of the instruments (Table 4.4). This exercise is important even in the absence of the social planner problem, since we assess the impact of different policies on health care expenditure, life expectancy, taxation and output and compare the results with the benchmark retirement age reform.

An increase of the consumption tax (τ_c) from 20% to 25% in order to finance increasing health care expenditure and pensions as a percentage of GDP, has a positive effect on output in our model. Compared to the benchmark case, the income tax rate decreases since now the government can balance its budget relying more on consumption taxation. The effects on the working and the non-working population are different, with both younger and older agents paying more consumption taxes, but younger agents' income is partially compensated by a decrease in income tax. This has a positive effect on output, since younger agents increase savings and older agents, who have high propensity to consume medical services, reduce health care expenditure due to lower disposable income. However, aggregate health care expenditure marginally increases.

Decreasing the pension replacement rate from $\chi = 32.6\%$ to 30% has positive effects on the economy and the sustainability of social provisions. Output increases, income tax rate falls significantly and as result saving increase as a percentage of GDP. This results not only due to reduced pension payments but also due to the reduction of health care expenditure as a percentage of GDP, since the disposable income of older agents that have higher propensity to consume medical services decreases. Zhao (2014) notes another aspect of the relation between health care expenditure and the generosity of social security. A more generous pension system, increases the expected value of future utility and agents are willing to spend more on health care in order to increase the probability of survival and take advantage of increased consumption in old age. This is true in our model as well, since households decrease health care expenditure when the pension replacement rate decreases.

Increasing the share of GDP devoted to health care infrastructure from $\xi = 1\%$ to 2% in order to lower the congestion effects of increasing demand of medical services and increasing population has interesting implications. As health care expenditure become more effective, households demand more services, resulting in an increase in health care expenditure, higher life expectancy and dependency ratios and reduced working hours lost due to illness. Hence a potential increase of health care infrastructure by the government caused by increased health care demand and the ageing population, results in greater health care expenditure are slightly worse dependency ratio. However, output increases partly because of increased productivity and partly because of reduced hours lost due to illness.

Finally, an increase in the percentage of out-of-pocket payments, from $q = 20\%$ to 21%, essentially a decrease in government subsidy of health care expenditure and decrease in the role of the NHS has positive effects. Output increases and the income tax is reduced, resulting in higher savings. Health care expenditure fall as a percentage of GDP, however the absolute value of health care expenditure increases resulting in higher life expectancy and less hours lost due to illness.

On face value, health care expenditure on services appear to be "on the flat of the curve" and any marginal increase in labour productivity and working hours is offset by the negative effect of an increase in income taxation and subsequently savings. The results suggest that the optimal policy for the UK government is to reduce the subsidy rate of services and increase the rate of investment in health care infrastructure. However, there are two caveats; first, health is not only productivity but also utility enhancing both on levels and the number of periods agents can derive utility from. Secondly the results depend on the assumptions regarding the productivity of health care expenditure as demonstrated by the comparative statics with respect to technological progress in the medical sector[16].

4.5 Concluding Remarks

This paper studied the effects of the retirement age reform on health care expenditure in a multi-period, overlapping generations framework. In the model, health care expenditure, life expectancy, pension payments and economic output are determined endogenously. In addition, we account for working hours lost due to illness and

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[16] In order to take these aspects of health care expenditure and social security into account we need to focus on welfare analysis which is beyond the scope of this paper.

congestion effects in the medical sector caused by increased demand of health care services and population growth. Hence, in contrast to the literature that studies the sustainability of social provisions, we incorporate the relation between labour supply and the level of health, accounting for sick time and the interaction between population ageing and congestion in the medical sector.

In the first part of the paper we provide evidence that health care expenditure and pension payments are increasing faster than GDP in developed countries, resulting in a higher share of GDP devoted to social provisions over the last decades. According to the literature, the fast increase of health care expenditure and pensions can be explained by income (Hall and Jones, 2007), technological progress (Fonseca et al., 2009) and social security provisions (Zhao, 2014) and greater life expectancy caused by technological progress (Cutler and McClellan, 2001) respectively. In our model, we take these factors into account in a general equilibrium model, however we contribute to the literature by taking into account working hours lost due to illness, congestion and studying the interaction between health care spending and postponing the retirement age reform.

In the second part of this paper, we describe the model and in the third part we demonstrate the calibration results for the UK economy in 2015. In part four, we perform simulations with respect to (i) an increase of the retirement age from 60 to 70 years, (ii) technological progress in the medical sector, (iii) TFP growth and (iv) government policies, in particular consumption taxation, pension replacement rate, investment in health care infrastructure and the rate of health care subsidy.

Our results suggest that households increase health care spending following an postponement of the retirement age, both because of an increase in income and as a response to working hours lost due to illness during older ages. Furthermore, in contrast to the literature we decompose the effects of technological progress on the level of health, probability of survival and sick time. Our results suggest that the future path of health care expenditure, longevity, pensions, output and taxation depends on the nature of technological progress in the medical sector. In particular, improvements in health that are unrelated with medical spending tend to reduce aggregate health care expenditure and increase output; improvements in the effectiveness of medical spending on the probability of survival worsens dependency ratios without significant effects on labour productivity or working hours lost due to illness and improvements with respect to the efficiency of medical spending on sick time, reduce working hours and increase output.

Finally, we examine different government policies and compare them to the benchmark retirement age reform. In our model, increasing the consumption tax rate, results in lower income taxation which increases saving and output and health care spending is reduced for retired agents since they face a reduction in their disposable income. With respect to the pension replacement rate, our results are in line with the literature (Zhao, 2014), resulting in lower medical spending and higher output when the replacement rate falls. Finally, according to our simulations, reducing the subsidy rate and increasing investment in health care infrastructure in order to increase the efficiency of medical spending has a positive effect on output and longevity, which suggests that the mix of government policy with respect to health care is suboptimal.

The model could be extended in various directions. First, we do not account for endogenous retirement as Ferreira and dos Santos (2013) and Zhao (2014), which adds another dimension when considering changes in the pension replacement rate. Households decide whether to retire or not taking into account their productivity, working hours lost due to illness and the benefits of retirement in order to make retirement decisions. Secondly, we do incorporate the leisure-labour choice explicitly in our model and its relation with the level of health as for instance in Kuhn et al. (2015). Lower levels of health could result in greater disutility from working, explaining in conjunction to labour productivity, labour supply decisions during later periods of life. Thirdly, studying the social planer's problem, in particular the second best government policy, would shed more light on the optimal level of health care subsidy, investment in health care infrastructure and the pension replacement rate.

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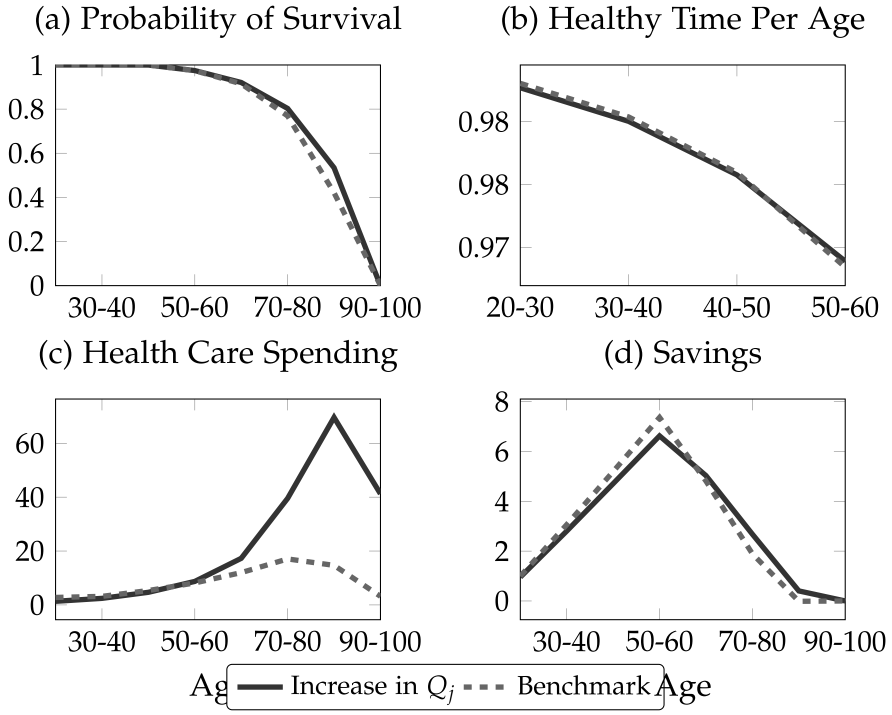
Appendix

4.A Figures

Here we present the simulation results for the individual variables of the probability of survival, healthy time, per capita health care spending as a percentage of GDP per capita and savings throughout the life-cycle of the individuals.

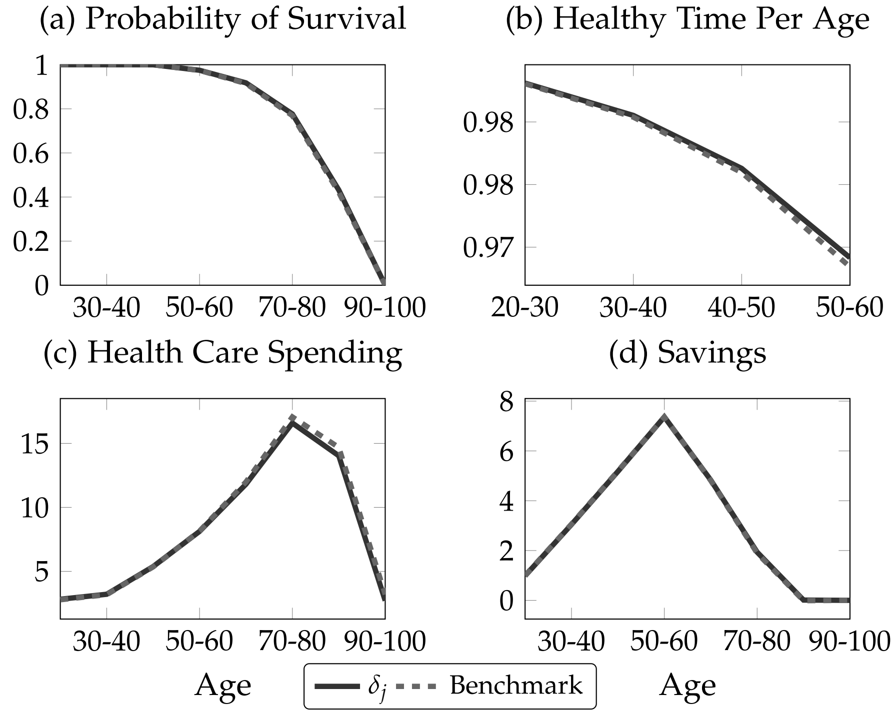
Ceteris Paribus Simulation

FIGURE 4.A.1: RESPONSE OF INDIVIDUAL VARIABLES AFTER A CHANGE IN Q_j



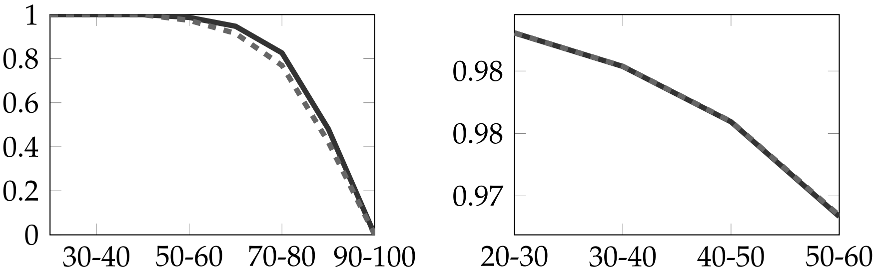
Notes: We assume that the effectiveness of health care spending on improving the level of health (Q_j) increase by 1% per year until 2046.

FIGURE 4.A.2: RESPONSE OF INDIVIDUAL VARIABLES AFTER A CHANGE IN δ_j



Notes: We assume that health deterioration (δ_j) decreases by 1% per year until 2046.

Figure 4.A.3: Response of Individual Variables after a change in a_p

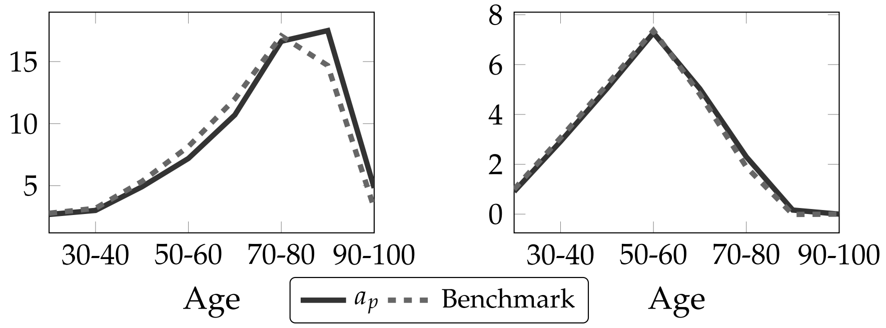


(a) Probability of Survival

(b) Healthy Time Per Age

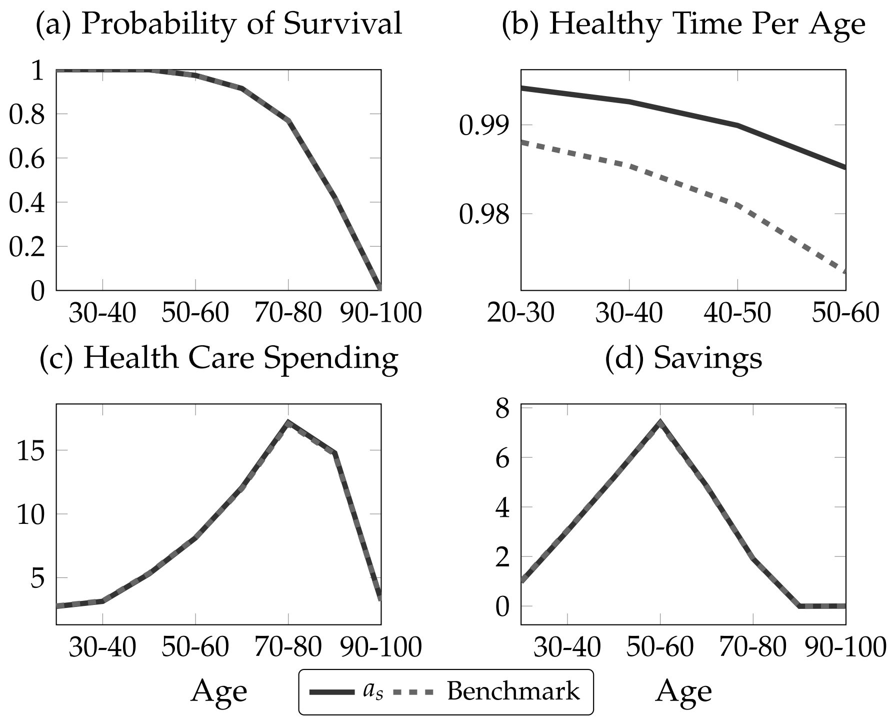
(c) Health Care Spending

(d) Savings



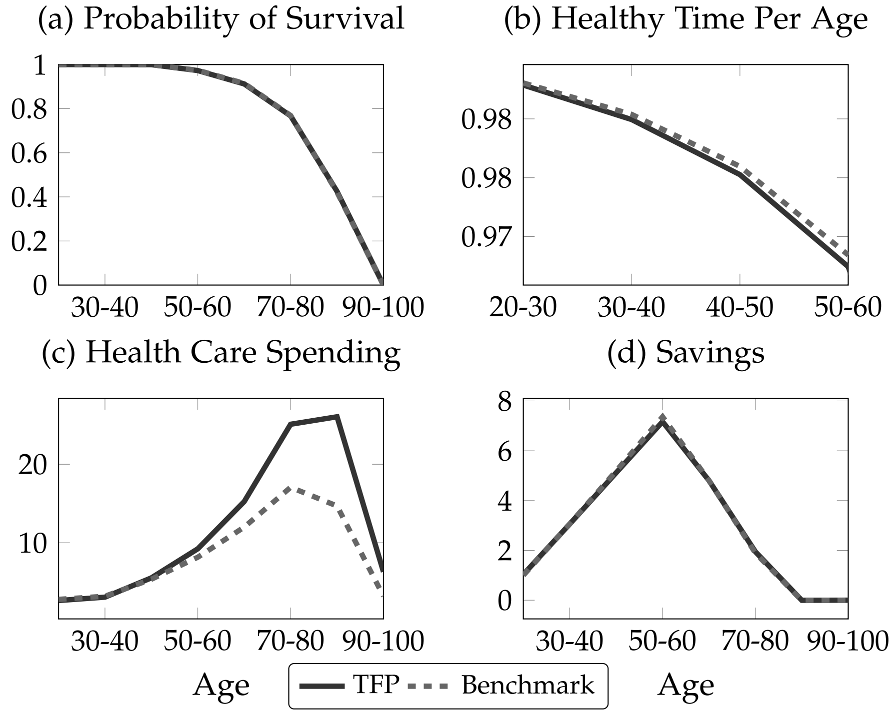
Notes: We assume that the effect of health on survival probability (a_p) increase by 1% per year until 2046.

FIGURE 4.A.4: RESPONSE OF INDIVIDUAL VARIABLES AFTER A CHANGE IN a_s



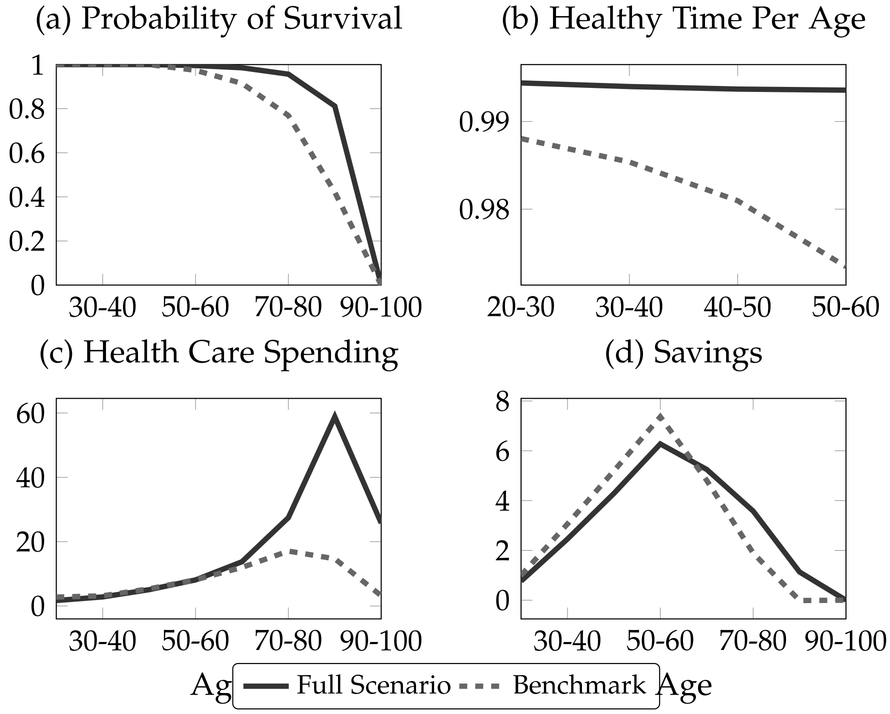
Notes: We assume that the effect of health on healthy time (a_s) increase by 1% per year until 2046.

Figure 4.A.5: Response of Individual Variables after a change in TFP



Notes: We assume that the Total Factor Productivity (A) increase by 1% per year until 2046.

FIGURE 4.A.6: RESPONSE OF INDIVIDUAL VARIABLES UNDER THE FULL SCENARIO



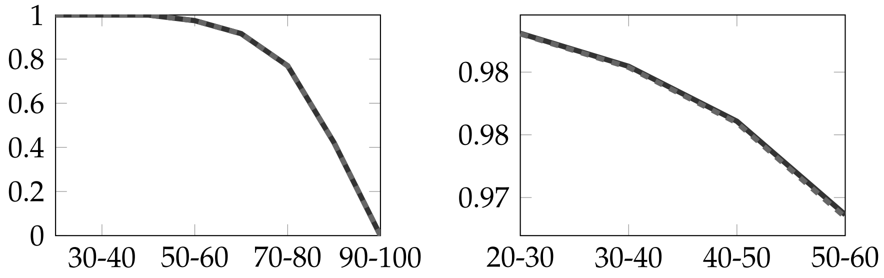
Notes: We assume that Q_j, a_p, a_s, A increase by 1% per year and δ_j decreases by 1% per year until 2046.

Policy Experiments

Figure 4.A.7: Response of Individual Variables After a Change in The Pension Replacement Rate

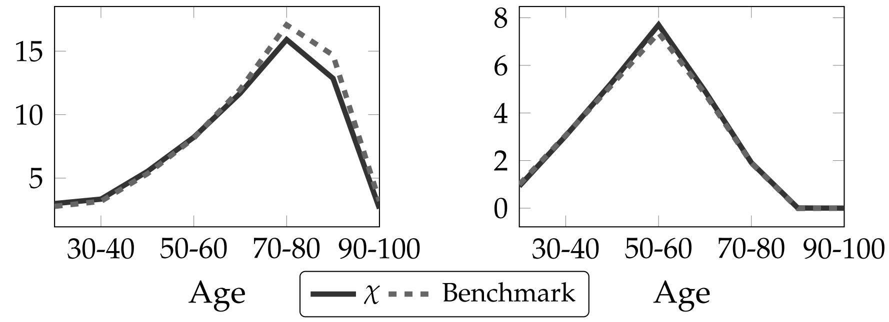
(a) Probability of Survival

(b) Healthy Time Per Age



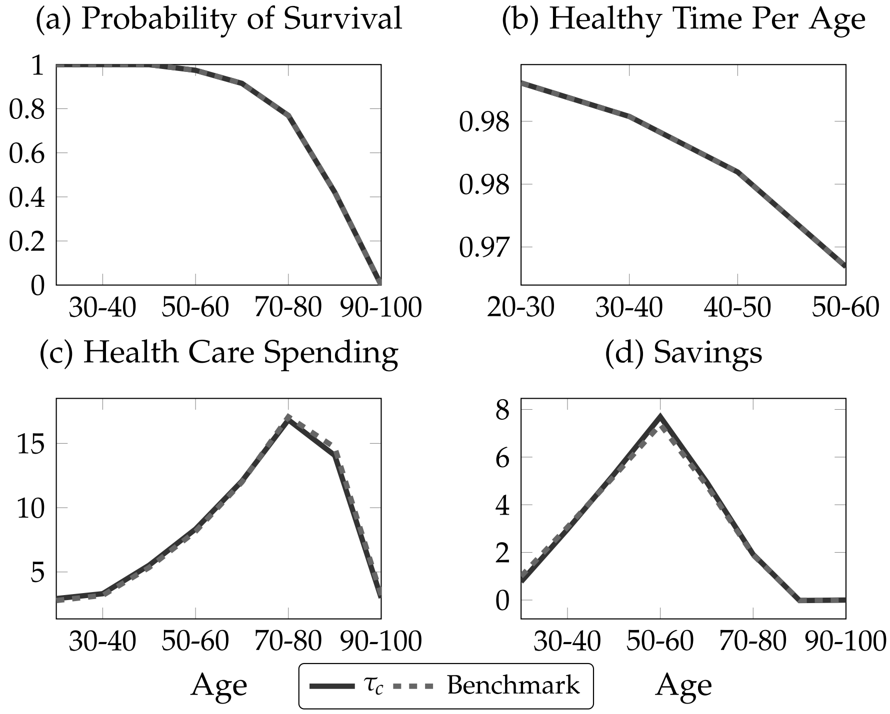
(c) Health Care Spending

(d) Savings



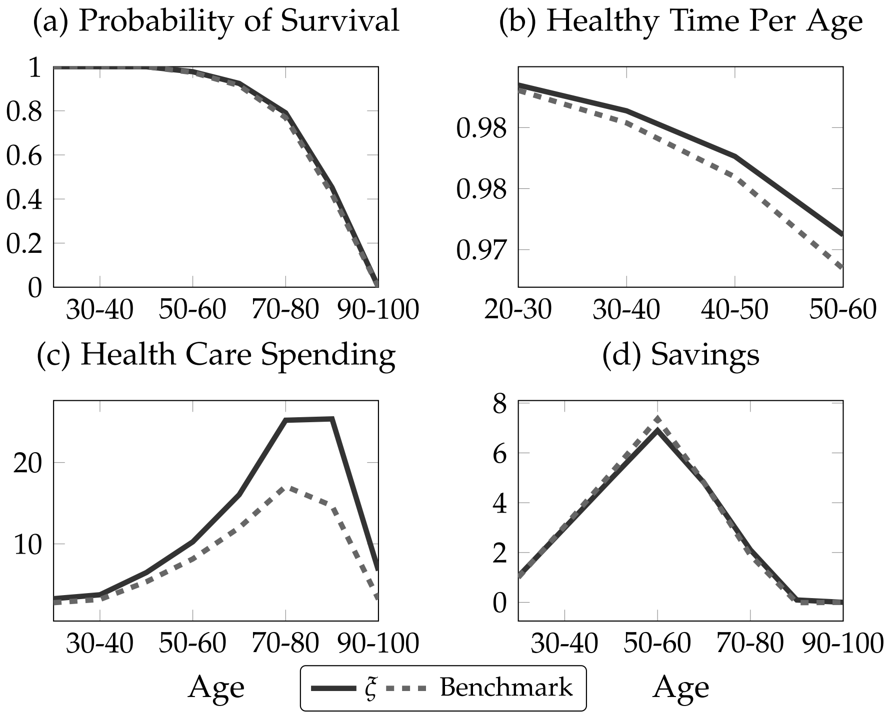
Notes: We assume that χ decreases from 32.6% to 30.0%.

Figure 4.A.8: Response of Individual Variables After a Change in the VAT



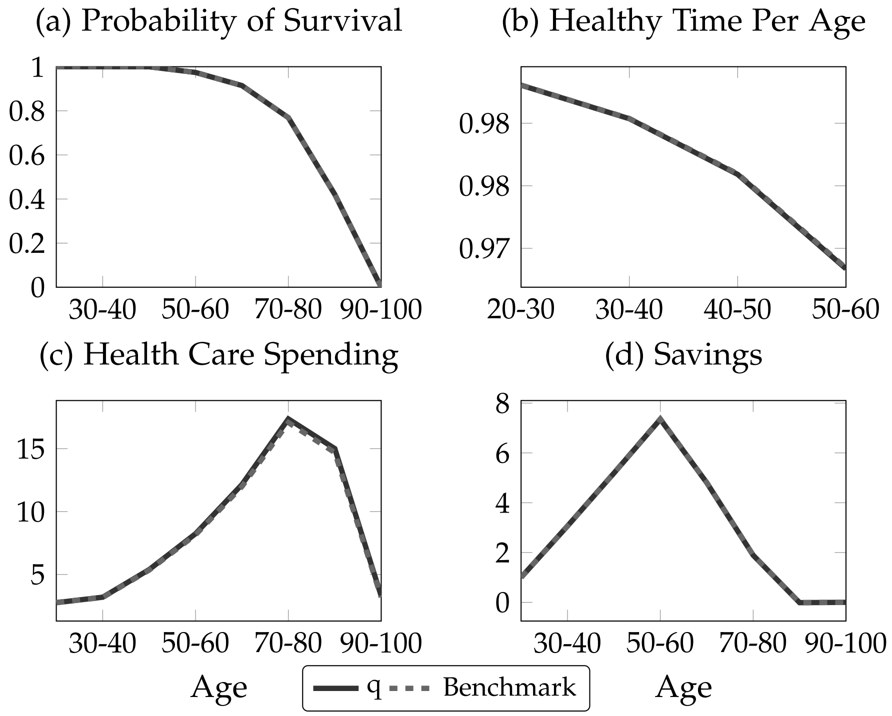
Notes: We assume that τ_c increases from 20.0% to 25.0%.

Figure 4.A.9: Response of Individual Variables After a Change Health Care Infrastructure Spending



Notes: We assume that ξ increases from 1.0% to 2.0%.

Figure 4.A.10: Response of Individual Variables After a Change Health Care Spending Subsidy Rate



Notes: We assume that q decreases from 20.0% to 19.0%.

Chapter 5

Conclusions

This thesis has been a collection of essays that focus on the macroeconomic effects of endogenous life expectancy in general equilibrium, overlapping generations models. We have shown that endogenous longevity has important implications on fiscal policy, capital accumulation and welfare, especially when we consider models where human capital accumulation, and in our models health-related human capital specifically, plays a significant role.

In chapter one, we studied the macroeconomic effects of obesity assessing the magnitude of the obesity externality and the macroeconomic and welfare implications of government intervention. In contrast to the results in the literature, we took into account the effects of weight on life expectancy and its subsequent effects on social provisions, in particular pensions and health care, to estimate more accurately the life-time fiscal impact of obesity. We found that the obesity externality is quantitatively small and the main source of it is the lower level of life-time contributions of obese individuals rather than high medical spending. In addition, although both tackling childhood obesity and taxing food consumption more heavily have positive effect on GDP, the welfare consequences of the latter towards the healthy percentiles of the BMI distribution suggests that taxing food consumption is not a Pareto improving policy.

In contrast, tackling childhood obesity has direct positive welfare implication, improving the quality of life and longevity of all agents in the economy.

In chapter two, we revisited the Ramsey problem of optimal taxation in an overlapping generations model where life expectancy and labour productivity is endogenous. We found that even if we consider the strong assumptions that ensure that the optimal capital income tax is zero in overlapping generations models, endogeneizing life expectancy results in a non-zero capital income tax. Furthermore, changes in life expectancy over time, as we observe in developed and developing countries through the ageing of the population, dictate an optimal *path* of capital income tax instead of an optimal level. This result has important implications for the design of the optimal tax policy, considering that improvements in medical technology that affect longevity do not appear to slow down and life expectancy is projected to increase even further in the future.

In chapter three, we studied the effects of the retirement age reform as a response of the ageing of the population on healthy care spending. We find that increasing the age of retirement induces agents to increase their medical spending in order to be fit to work at older ages. This has direct and indirect effects on government spending since (i) the government subsidizes health care spending and (ii) dependency ratios deteriorate because of higher medical spending that has indirect effects on life expectancy. Hence, we show that policy makers need to take into account the side effects of increasing the compulsory retirement age on health care spending in order to estimate accurately the net fiscal impact of such reforms.