# Harsh occupations, life expectancy and social security

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**Abstract**

We study the optimal design of a social security system when individuals differ in longevity and occupation. Both occupations yield the same wage and the occupation is given. Longevity is private information but it is publicly known that there is a higher proportion of short-lived workers in the harsh occupation. We show that there is a case for differentiating the pension policy by occupation. The short-lived workers in the safe occupation are however often made worse-off, even when the social objective incorporates weights to redress the implicit redistribution from short- to long-lived individuals that the unweighted utilitarian objective entails. In the maximin solution all short-lived workers achieve the same utility with those in the safe occupation consuming the most when young and retiring the earliest. This is achieved by taxing – often quite heavily – their savings and their earnings from prolonging activity.

Keywords: longevity, retirement, harsh occupations, tagging

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# 1 Introduction

Social security systems are under increased fiscal pressure due to the impact of population ageing. With increasing life expectancies it seems reasonable to require individuals to work longer. In recent years several countries have increased the legal age of retirement and other countries are considering doing so. However, the chances of reaching and living retirement in good health differ significantly among individuals. Cambois et al. (2011) show in addition that the chances of living longer and in good health are closely correlated with occupation. In this paper we study the optimality of allowing the pension policies, and in particular the retirement age, to differ by occupation.

Special pension provisions are indeed a feature of many OECD economies - as many as 18 OECD member countries have special pension schemes - and are the subject of an on-going public policy debate. Zaidi and Whitehouse (2009) discuss their incidence, structure and justification. They mention that such provisions have historically been justified on the grounds that individuals in hazardous jobs, such as underground mining, merit special treatment because this type of work increases mortality and reduces life expectancy, thus shortening the time during which retirement benefits can be enjoyed. They highlight that the most common form is that of a collective concession, where a whole sector (such as underground mine workers, sailors, airline workers and artists) is granted a special treatment in the calculation of pensions and thus provisions towards early retirement.

If the correlation between longevity and occupation were perfect, it would suffice to have specific pension provisions for each occupation. Unfortunately, things are less simple when policy administrators are unable to observe individual longevity and the correlation between longevity and occupation fails to be perfect. In this paper we discuss the design of special pension schemes in an asymmetric information framework. Individuals are characterized by their longevity and occupation. They are better informed about their longevity prospects. There is however some (imperfect) correlation between longevity and occupation, and occupation is observable.

We adopt a simple setting with two periods. During the first period, of identical length for all, the individuals work, consume and save. During the second period, of uneven length depending on longevity, individuals work, retire and consume the sum of their earnings in second period, their savings and public pension benefits (if they receive any). To make the presentation simple, we assume that there are only two occupations and two longevity types. All individuals have the same productivity but those with a harsh occupation face a higher probability of a short life than those with a safe occupation. Longevity is private information and is learned by the worker sometime in the first period. We make the reasonable assumption that the disutility of prolonging activity in the second period is inversely related to longevity. In other words, a worker who expects to live longer has a lower disutility from delaying retirement than one with a shorter life expectancy. We employ an optimal non-linear taxation approach: i.e. we identify the optimal bundle of consumption in both periods and retirement age for each type of individual, and show how the optimal solution can be implemented via a non-linear tax/transfer scheme.

We assume that the wage earned in both occupations is the same and that the occupation is given. We do so to focus on the insurance aspect of the pension policies and abstract from the standard redistribution role associated with heterogeneous wages. In the real world, it is common to observe workers engaged in harsh occupations and yet earning less than workers in safer occupations. Cambois et al. (2011) show that low-skilled manual workers live fewer years and more years in poorer health. Accordingly, we discuss the implications of allowing the wages to differ across occupations.

We consider and compare different information and policy settings. We derive first the laissez-faire solution in the absence of any public pension policy. We consider next the first-best full information benchmark. When longevity varies across individuals and utility is additive across periods the traditional utilitarian criterion implies some redistribution from short- to long-lived individuals. We incorporate weights in the utilitarian social objective, to redress to some extent the bias towards long-lived individuals the unweighted utilitarian social objective entails, and explore the implications for the optimal social security policy of letting the weights vary. We then analyse two second-best problems: in the first case the social security policy is constrained to be the same across occupations (i.e. special pension provisions for harsh occupations are ruled out); in the second case tagging by occupation is allowed. We show that short-lived workers face marginal distortions on savings and prolonging activity. They are induced to consume relatively more when young than when old. This result is in the same vein as those of Fleurbaey et al. (2011, 2013) who show that if one takes an ex post viewpoint priority should be given to first-period consumption. We also show that there is a case for differentiating the social security policy by occupation.

The public economics literature has not dwelt much on the relationship between occupation, longevity and retirement. Previous contributions have explored the link between disability and retirement. Cremer et al. (2004, 2007) study the design of optimal social security schemes when disability is not readily observable. They use two devices to elicit information on disability: costly disability tests and self-selection. A downward distortion on retirement age (i.e. earlier retirement) for those who claim to be disabled is shown to be a way to prevent healthy workers from mimicking disabled ones when disability is not observable. Cremer et al. (2007) show that this downward distortion on retirement age can be partially relaxed by introducing error-proof but costly disability tests. In a companion paper to this one, Pestieau and Racionero (2013) extend Cremer et al. (2007) by incorporating occupations, and assuming imperfect correlation between disability and occupation. They explore the possibility of differentiating the social security policy by occupation, and compare the results with those achieved with disability tests. Their numerical simulations illustrate that tagging by occupation is preferred to testing when the audit technology is relatively expensive and/or the ratio of disabled to healthy workers differs markedly across occupations. Both the healthy and disabled workers in the harsh occupation are better off in the tagging solution, consuming more and retiring earlier, than their counterparts in the safe occupation. When horizontal equity is imposed so that disabled workers achieve the same level of utility regardless of their occupation, those in the harsh occupation are induced to retire later than those in the safe occupation but are compensated with larger benefits.

In this paper we abstract from tests and focus on another dimension of health, namely longevity. As highlighted above, the traditional utilitarian social objective induces redistribution from short- to long-lived individuals in our setting with differential longevity. This was not the case under differential health status, where the utilitarian objective implied redistribution from healthy to disabled individuals. In order to partially redress the implicit redistribution towards long-lived individuals the unweighted utilitarian objective entails we explore the implications of increasing the weight on the short-lived individuals and compare with the maximin solution.

The rest of the paper is organised as follows. In Section 2 we present the model and provide the laissez-faire solution. In section 3 we derive the first-best benchmark solution for a weighted utilitarian social objective. In section 4 we analyze the second-best asymmetric information problem: first without tagging (i.e. when the social security policy is common across occupations), and then with tagging (i.e. when the social security policy is allowed to differ by occupation). We study also the particular cases of three-types societies (in which one occupation is composed of individuals of a single longevity type) and the maximin objective. We conclude in section 5. Throughout the paper we refer to numerical simulations for illustrative purposes but for convenience we include the simulations in the appendix.

## 2 The model

We consider a society in which individuals differ in longevity and occupation. The longevity, represented by $\ell_i$, is private information. We assume that individuals can be either long-lived or short-lived:[1] $\ell_L > \ell_S$, where $L$ and $S$ stand for long-lived and short-lived, respectively. The occupation, represented by subscript $j$ ($j = 1, 2$), is observable. $n_j$ stands for the proportion of workers in occupation $j$ and $p_j$ represents the proportion of workers in occupation $j$ that are short-lived. We assume that $p_1 > p_2$. Accordingly, we refer to occupation 1 as harsh and occupation 2 as safe.

We take occupation as given and assume that both occupations yield the same wage $w$. This assumption allows us to focus on the insurance aspect of the pension schemes and abstract from the standard redistribution associated with heterogeneous wages. In the simulations we also consider heterogeneous wages and illustrate how the results change when wages are allowed to vary across occupations.[2]

Individuals live for 2 periods. In the first period, of length normalized to 1, individuals work full time and earn wage $w$, consume $c_{ij}$ and save $s_{ij}$. At some point in the first period individuals learn their longevity type. In the second period, of length $\ell_i$, individuals work for an endogenous amount of time $z_{ij}$ and consume $d_{ij}$, which, in the absence of public pensions, is financed from their second-period earnings and savings (i.e. there are no bequests).

There are hence four types of individuals $ij$ ($i = S, L$ and $j = 1, 2$) with preferences represented by the following utility function:

$$U_{ij} = u(c_{ij}) + \ell_i u(d_{ij}) - v(z_{ij}; \ell_i) \tag{1}$$

[1] At the outset all individuals are alike even though as time goes by some of them realise that they will have a shorter life than others. In other words, we do not allow for differences in longevity that are common knowledge at the start. We indeed observe such differences accross genders or location.

[2] Endogenous occupational choice will be considered in further research. There are in fact complex interrelations between the innate ability, the quality of occupation and the earnings of workers that require a more ambitious model to be addressed.

where, as mentioned above, $c_{ij}$ represents first-period consumption, $d_{ij}$ represents second-period consumption and $z_{ij}$ represents second-period labour supply. The length of active life is therefore $1 + z_{ij}$. The utility of consumption in both first and second periods function $u(.)$ is assumed to be strictly increasing and concave (i.e. $u'(.) > 0$ and $u''(.) < 0$). The disutility function of prolonging activity $v(.)$ is assumed to be increasing and convex (i.e. $v'(.) > 0$ and $v''(.) > 0$). We also assume that this disutility depends on the longevity of individuals $\ell_i$ and, in particular, that the marginal disutility of working longer is higher for short-lived individuals: $v'(z;\ell_S) > v'(z;\ell_L)$ for all $z$. The marginal rates of substitution of first- for second-period consumption, and of labor for consumption in second period, are given respectively by

$$MRS_{cd}^{ij} = \frac{u'(c_{ij})}{u'(d_{ij})} \text{ and } MRS_{zd}^{ij} = \frac{v'(z_{ij};\ell_i)}{u'(d_{ij})}. \tag{2}$$

The latter implies that the indifference curve of the short-lived individuals is steeper at any given allocation in the $(z, d)-$space.

The social security policy consists of a bundle $(c_{ij}, d_{ij}, z_{ij})$ of consumption, in first and second periods, and of labour supply in second period (i.e. retirement age) for each individual $ij$. This social security policy can be implemented by a non-linear tax on savings $t(s_{ij})$ and a non-linear tax on prolonging activity $T(z_{ij})$. The consumer $ij$'s problem under the non-linear tax schedules $t(s_{ij})$ and $T(z_{ij})$ can be written as:

$$\max_{s_{ij}, z_{ij}} \quad u(w - s_{ij}) + \ell_i u(\frac{s_{ij} - t(s_{ij}) + wz_{ij} - T(z_{ij})}{\ell_i}) - v(z_{ij};\ell_i).$$

The first-order conditions (hereafter FOCs) are:

$$FOC(s_{ij}) \quad : \quad u'(c_{ij})(-1) + \ell_i u'(d_{ij}) \frac{1}{\ell_i}\left(1 - t'(s_{ij})\right) = 0, \tag{3}$$

$$FOC(z_{ij}) \quad : \quad \ell_i u'(d_{ij}) \frac{1}{\ell_i}\left(w - T'(z_{ij})\right) - v'(z_{ij};\ell_i) = 0. \tag{4}$$

Rearranging, we obtain that the marginal taxes on savings and on prolonging activity (i.e. postponing retirement) are, respectively:[3]

$$t'(s_{ij}) = 1 - \frac{u'(c_{ij})}{u'(d_{ij})} \text{ and } T'(z_{ij}) = w - \frac{v'(z_{ij};\ell_i)}{u'(d_{ij})}. \tag{5}$$

[3] The marginal tax on labour earnings from prolonging activity is:

$$T'(wz_{ij}) = 1 - \frac{v'(z_{ij};\ell_i)}{wu'(d_{ij})}.$$

In a market economy, each individual $ij$ chooses $s_{ij}$ and $z_{ij}$ to maximize (1) subject to first- and second-period budget constraints, $c_{ij} + s_{ij} = w$ and $\ell_i d_{ij} = s_{ij} + w z_{ij}$ respectively:

$$\max_{s_{ij}, z_{ij}} u(w - s_{ij}) + \ell_i u(\frac{s_{ij} + w z_{ij}}{\ell_i}) - v(z_{ij}; \ell_i).$$

The FOCs are:

$$FOC\left(s_{ij}\right) \quad : \quad u'\left(c_{ij}\right)(-1) + \ell_i u'\left(d_{ij}\right)\frac{1}{\ell_i} = 0, \tag{6}$$

$$FOC\left(z_{ij}\right) \quad : \quad \ell_i u'\left(d_{ij}\right)\frac{1}{\ell_i} w - v'(z_{ij}; \ell_i) = 0. \tag{7}$$

Rearranging:

$$u'\left(c_{ij}\right) = u'\left(d_{ij}\right) = \frac{v'\left(z_{ij}; \ell_i\right)}{w}. \tag{8}$$

The bundle $(c_{ij}, d_{ij}, z_{ij})$ depends only on longevity (i.e. we can ignore the subscript for occupation $j$ in the laissez-faire solution) and individuals smooth consumption between first and second periods (i.e. $c_i = d_i$ for each $i = S, L$). The relationship between the particular combinations chosen, and the levels of utility achieved, by individuals with different longevity is ambiguous without specifying particular functional forms.

We assume in the following that living longer is preferable. Differentiating $U_{ij}$ with respect to $\ell_i$, we have:

$$\frac{\partial U_{ij}}{\partial \ell_i} = u(d_{ij}) - u'(d_{ij}) d_{ij} - \frac{\partial v(z_{ij}; \ell_i)}{\partial \ell_i}.$$

It follows that $u\left(d\right) > u'\left(d\right) d$ is sufficient to ensure that utility increases with longevity, which is a standard assumption.[4] Additional conditions on the disutility of prolonging activity $v(z; \ell)$ are required to ensure that individuals enjoy some positive amount of time in retirement.

## 3 The first best: incorporating weights

It is important to notice first that employing the traditional unweighted utilitarian social objective may have undesirable consequences when longevity varies across individuals. Indeed, with additive utilities the utilitarian criterion implies some redistribution from the short- to the long-lived individuals. Short-lived individuals are subject to a double penalty: they live fewer years and are made to subsidize those who live longer.[5] In order to partially redress the implicit redistribution

[4] See Eeckhoudt and Pestieau (2008).
[5] See Pestieau and Ponthière (2012).

towards long-lived individuals that the unweighted utilitarian social objective entails we incorporate social weights. We denote by $\gamma_i$ the weight on individuals with longevity $\ell_i$ $(i = S, L)$. We assume $\gamma_S = \gamma \geq 1/2$ (and $\gamma_L = 1 - \gamma \leq 1/2$), where $\gamma$ could be adjusted in such a way that the utilities of the two types are equalized if so desired. The Lagrangian for the first-best problem is:

$$\begin{aligned}\pounds \quad &= \quad \sum_{j=1,2} n_j \left\{ \gamma_L \left(1 - p_j\right) \left[u(c_{Lj}) + \ell_L u(d_{Lj}) - v(z_{Lj}; \ell_L)\right] + \gamma_S p_j \left[u(c_{Sj}) + \ell_S u(d_{Sj}) - v(z_{Sj}; \ell_S)\right]\right\} \\ &\quad + \mu \sum_{j=1,2} n_j \left\{ \left(1 - p_j\right) \left[\left(1 + z_{Lj}\right) w - c_{Lj} - \ell_L d_{Lj}\right] + p_j \left[\left(1 + z_{Sj}\right) w - c_{Sj} - \ell_S d_{Sj}\right]\right\},\end{aligned}$$

where $\mu$ is the Lagrangian multiplier associated with the budget constraint. Rearranging the FOCs we obtain for each type $ij$:

$$u'\left(c_{ij}\right) = u'\left(d_{ij}\right) = \frac{v'\left(z_{ij}; \ell_i\right)}{w} = \frac{\mu}{\gamma_i}. \tag{9}$$

As in the laissez-faire, the bundle $(c_{ij}, d_{ij}, z_{ij})$ depends only on longevity (i.e. we can also ignore the subscript for occupation $j$) and involves consumption smoothing between first and second periods (i.e. $c_i = d_i$ for each $i = S, L$). If both long- and short-lived individuals receive the same weight in the utilitarian social objective the first-best solution is characterized by the same consumption levels for all (i.e. $c_L = d_L = d_S = c_S$) and $v'\left(z_S; \ell_S\right) = v'\left(z_L; \ell_L\right)$, which implies earlier retirement for short-lived individuals (i.e. $z_S < z_L$) since they have a higher marginal disutility from prolonging activity. When more weight is placed on short-lived individuals in the social objective (i.e. $\gamma > 1/2$), long-lived individuals consume less in both periods $c_L = d_L < d_S = c_S$. In addition, $v'\left(z_S; \ell_S\right) < v'\left(z; \ell_L\right)$ and the gap between retirement ages $z_L$ and $z_S$ increases. If longevity is not observable the incentive for type-$L$ individuals to mimic type-$S$ individuals, which is already present with equal weights, is exacerbated as more weight is placed on short-lived individuals. Given the pattern of consumption and retirement in the first-best type-$L$ individuals would be better off with the package offered to type-$S$ individuals:

$$u(c_L) + \ell_L u(d_L) - v(z_L; \ell_L) < u(c_S) + \ell_L u(d_S) - v(z_S; \ell_L).$$

## 4 The second best: common versus differentiated policies

We have just shown that the first-best solution is not feasible when longevity is private information. The social planner needs to design the social security policy so that individuals reveal their true types. We assume first, as a benchmark, that the social planner does not have or cannot use information about occupation: i.e. the same social security policy applies regardless of occupation. We then allow the social planner to differentiate the social security policy by occupation when information about occupation is available and can be used as a tag (accordingly, we call this case tagging by occupation).

### 4.1 Common social security policy across occupations

The Lagrangian for this second-best problem is:

$$\begin{aligned}
\pounds \;=\; & \sum_{j=1,2} n_j \left\{ \gamma_L \left(1-p_j\right)\left[u(c_L)+\ell_L u(d_L)-v(z_L;\ell_L)\right] + \gamma_S p_j \left[u(c_S)+\ell_S u(d_S)-v(z_S;\ell_S)\right] \right\} \\
& +\mu \sum_{j=1,2} n_j \left\{ \left(1-p_j\right)\left[\left(1+z_L\right)w - c_L - \ell_L d_L\right] + p_j \left[\left(1+z_S\right)w - c_S - \ell_S d_S\right] \right\} \\
& +\lambda \left[u(c_L)+\ell_L u(d_L)-v(z_L;\ell_L)-u(c_S)-\ell_L u(d_S)+v(z_S;\ell_L)\right],
\end{aligned}$$

where $\lambda$ represents the Lagrangian multiplier associated with the self-selection constraint that is incorporated to ensure that long-lived individuals do not have incentives to mimic short-lived ones. Rearranging the FOCs, and using $n_L = n_1\left(1-p_1\right)+n_2\left(1-p_2\right)$ for total number of long-lived individuals in the population and $n_S = n_1 p_1 + n_2 p_2$ for total number of short-lived individuals in the population, we obtain:

$$u'\left(c_L\right) = u'\left(d_L\right) = \frac{v'(z_L;\ell_L)}{w} = \frac{\mu}{1-\gamma+\frac{\lambda}{n_L}} \tag{10}$$

for long-lived individuals, and

$$u'\left(c_S\right) = \frac{\mu}{\gamma-\frac{\lambda}{n_S}},\; u'\left(d_S\right) = \frac{\mu}{\gamma-\frac{\lambda}{n_S}\frac{\ell_L}{\ell_S}} \text{ and } v'(z_S;\ell_S) = \frac{1}{\gamma}\left(\mu w + \frac{\lambda}{n_S} v'(z_S;\ell_L)\right) \tag{11}$$

for short-lived individuals. Hence:

$$\frac{u'\left(c_L\right)}{u'\left(d_L\right)} = 1 \text{ and } \frac{v'(z_L;\ell_L)}{u'\left(d_L\right)} = w, \tag{12}$$

$$\frac{u'\left(c_S\right)}{u'\left(d_S\right)} < 1 \text{ and } \frac{v'(z_S;\ell_S)}{u'\left(d_S\right)} = w + \frac{\lambda}{\gamma n_S}\left(\frac{v'(z_S;\ell_L)}{u'\left(d_S\right)} - \frac{\ell_L}{\ell_S} w\right) < w. \tag{13}$$

The second-best solution implies no distortion on long-lived individuals but distortions at both margins - savings and prolonging activity - for short-lived ones .

The second-best solution is accordingly characterized by $c_L = d_L$ (i.e. consumption smoothing for long-lived individuals) and $c_S > d_S$ (higher first- than second-period consumption for short-lived individuals). In principle any relationship between $c_L$ and $c_S$, and between $d_L$ and $d_S$, is possible depending on the particular value of weight $\gamma$:

$$c_L > c_S \Leftrightarrow \gamma < \frac{1}{2}\left(1 + \frac{\lambda}{n_L n_S}\right),$$

$$d_L > d_S \Leftrightarrow \gamma < \frac{1}{2}\left[1 + \frac{\lambda}{n_L n_S}\left(n_S + n_L \frac{\ell_L}{\ell_S}\right)\right].$$

If both long- and short-lived individuals receive the same weight the first-best solution implies more consumption for long-lived ones: $c_L = d_L > c_S > d_S$. If the weight $\gamma$ placed on short-lived individuals is sufficiently large, the inequalities between $c_L$ and $c_S$, and between $d_L$ and $d_S$, can in principle be reversed. In order to better illustrate the implications of letting the weight placed on short-lived individuals vary we perform numerical simulations. The numerical results are provided in the appendix but we briefly summarize some relevant aspects here.

In Table 2 we provide the results for the second-best problem without tagging for different social weights. The marginal tax rates on savings and prolonging activity imposed on short-lived individuals increase with the value of social weight $\gamma$. Taking the unweighted utilitarian social objective as benchmark, as the weight placed on short-lived individuals increases, $c_S$ increases, $c_L$ and $d_L$ (with $c_L = d_L$) decrease, $d_S$ decreases - with the decrease in $d_S$ being more pronounced than the decrease in $d_L$ involving a larger gap between $d_L$ and $d_S$ -, $R_L$ increases and $R_S$ decreases, where $R$ stands for retirement age.

## 4.2 Tagging by occupation

Many pension policies disregard possible longevity differences across occupations and establish the same retirement age and benefits for all workers regardless of their occupation. We explore now an alternative second-best solution that seeks to exploit the differences in average longevity across occupations. In particular we analyse whether, and if so how, the social security policy should differ by occupation. The main distinction with respect to the second-best benchmark in which the planner provides a common social security policy for all occupations is that now there is one self-selection constraint for each occupation. The Lagrangian is now:

$$
\begin{aligned}
\pounds = {} & \gamma_L \sum_{j=1,2} n_j \left(1-p_j\right) \left[u(c_{Lj}) + \ell_L u(d_{Lj}) - v(z_{Lj};\ell_L)\right] \\
& + \gamma_S \sum_{j=1,2} n_j p_j \left[u(c_{Sj}) + \ell_S u(d_{Sj}) - v(z_{Sj};\ell_S)\right] \\
& + \mu \sum_{j=1,2} n_j \left\{\left(1-p_j\right)\left[\left(1+z_L\right)w - c_L - \ell_L d_L\right] + p_j\left[\left(1+z_S\right)w - c_S - \ell_S d_S\right]\right\} \\
& + \lambda_1 \left[u(c_{L1}) + \ell_L u(d_{L1}) - v(z_{L1};\ell_L) - u(c_{S1}) - \ell_L u(d_{S1}) + v(z_{S1};\ell_L)\right] \\
& + \lambda_2 \left[u(c_{L2}) + \ell_L u(d_{L2}) - v(z_{L2};\ell_L) - u(c_{S2}) - \ell_L u(d_{S2}) + v(z_{S2};\ell_L)\right]
\end{aligned}
$$

where $\lambda_j$ is the Lagrange multiplier associated with the self-selection constraint that ensures that long-lived individuals do not have incentives to mimic short-lived ones in each occupation $j$ ($j = 1,2$).

Rearranging the FOCs for long-lived individual types $Lj$ ($j = 1,2$) we obtain:

$$
u'\left(c_{Lj}\right) = u'\left(d_{Lj}\right) = \frac{v'\left(z_{Lj};\ell_L\right)}{w} = \frac{\mu}{1-\gamma+\frac{\lambda_j}{n_j(1-p_j)}}. \tag{14}
$$

Therefore,

$$
\frac{u'\left(c_{Lj}\right)}{u'\left(d_{Lj}\right)} = 1 \text{ and } \frac{v'\left(z_{Lj};\ell_L\right)}{u'\left(d_{Lj}\right)} = w, \tag{15}
$$

which implies no distortion on long-lived workers in both occupations. This does not mean however that long-lived workers in different occupations receive the same treatment. The particular bundle $(c_{Lj}, d_{Lj}, z_{Lj})$ assigned to long-lived workers in occupation $j$ depends on the particular proportions of short- and long-lived workers in their occupation: there is consumption smoothing for long-lived individuals in both occupations - i.e. $c_{Lj} = d_{Lj}$ for each $j$ - but the consumption level depends on the longevity distributions in each occupation. We can however show that if long-lived workers in a particular occupation consume more they also retire earlier, and are hence better-off, than their counterparts in the other occupation.

Rearranging the FOCs for short–lived individual types $Sj$ ($j = 1,2$):

$$
u'\left(c_{Sj}\right) = \frac{\mu}{\gamma - \frac{\lambda_j}{n_j p_j}},\ u'\left(d_{Sj}\right) = \frac{\mu}{\gamma - \frac{\lambda_j}{n_j p_j}\frac{\ell_L}{\ell_S}} \text{ and } v'\left(z_{Sj};\ell_S\right) = \frac{1}{\gamma}\left(\mu w + \frac{\lambda_j}{n_j p_j} v'\left(z_{Sj};\ell_L\right)\right). \tag{16}
$$

Hence,

$$
\frac{u'\left(c_{Sj}\right)}{u'\left(d_{Sj}\right)} < 1 \text{ and } \frac{v'\left(z_{Sj};\ell_S\right)}{u'\left(d_{Sj}\right)} = w + \frac{\lambda_j}{\gamma n_j p_j}\left(\frac{v'\left(z_{Sj};\ell_L\right)}{u'\left(d_{Sj}\right)} - \frac{\ell_L}{\ell_S} w\right) < w, \tag{17}
$$

which implies distortion at both margins - savings and prolonging activity - for short-lived workers in both occupations. The extent of the distortion, the particular bundle and the level of utility achieved depend on the proportions of short- and long-lived individuals in each occupation.

In Table 3 we provide numerical simulations for the second-best problem with tagging. We do so for different social weights - $\gamma = 0.5$ and $\gamma = 2/3$ - and for different distributions - $(p_1, p_2) = (0.6, 0.4)$ and $(p_1, p_2) = (0.8, 0.2)$. Both short- and long-lived workers in the harsh occupations are made better off, while those in the safe occupation are made worse-off, by tagging. The differences are more pronounced when the proportion of short-lived individuals in the harsh occupation increases (i.e. occupation 1 becomes harsher). Short-lived workers in the harsh occupation consume more in both periods, and retire earlier, than their counterparts in the safe occupation. The marginal distortions imposed on the short-lived workers in the safe occupation are larger at both margins than those imposed on their counterparts in the harsh occupation, and the difference increases when occupation 1 becomes harsher (in particular, the distortions on type-$S2$ increase while those on type-$S1$ decrease). However, the consumption and retirement patterns of the short-lived types, and the distortions imposed on them, differ more markedly as a result of an increase in the social weight placed on short-lived individuals. When $\gamma$ increases from 0.5 to 2/3 there is a decrease in second-period consumption for both short-lived types, which is more pronounced for those in the safe occupation. Long-lived workers in the harsh occupation consume more in both periods and retire earlier, and are hence better off, than their counterparts in the safe occupation. Their treatments differ more when occupation 1 is relatively harsher, but they differ even more markedly when the social weight placed on short-lived individuals increases from 0.5 to 2/3. For the distributions considered in Table 3, type-$L1$ individuals are made better off and type-$S2$ individuals are made worse off by an increase in the weight placed on short-lived types. This effect is more pronounced as the proportion of short-lived workers in the harsh occupation increases.

### 4.2.1 Three-types societies

In order to shed more light on the results we focus on three-types societies, of the kind analysed by Akerlof (1978), in which one of the occupations consists of workers of the same longevity type. Given that $p_1 > p_2$ there are only two possible cases: either $p_2 = 0$ (i.e. all workers in the safe occupation are long-lived) or $p_1 = 1$ (i.e. all workers in the harsh occupation are short-lived).

If all workers in the safe occupation are long-lived the only relevant SSC is the one that relates long- and short-lived individuals in the harsh occupation. For long-lived workers in the safe and the harsh occupations we have, respectively:

$$u'(c_{L2}) = u'(d_{L2}) = \frac{v'(z_{L2};\ell_L)}{w} = \frac{\mu}{1-\gamma}, \tag{18}$$

$$u'(c_{L1}) = u'(d_{L1}) = \frac{v'(z_{L1};\ell_L)}{w} = \frac{\mu}{1-\gamma+\frac{\lambda_1}{n_1(1-p_1)}}. \tag{19}$$

For the short-lived individuals, who all work in the harsh occupation, we have:

$$u'(c_{S1}) = \frac{\mu}{\gamma-\frac{\lambda_1}{n_1p_1}},\ u'(d_{S1}) = \frac{\mu}{\gamma-\frac{\lambda_1}{n_1p_1}\frac{\ell_L}{\ell_S}} \text{ and } v'(z_{S1};\ell_S) = \frac{1}{\gamma}\left(\mu w+\frac{\lambda_1}{n_1p_1}v'(z_{S1};\ell_L)\right). \tag{20}$$

It follows that $c_{L1} = d_{L1} > c_{L2} = d_{L2}$, which together with $z_{L1} < z_{L2}$, implies $U_{L1} > U_{L2}$. Hence, the long-lived workers in the harsh occupation are better off than those in the safe occupation when all workers in the safe occupation are long-lived. For equal weights we have $c_{L1} = d_{L1} > c_{L2} = d_{L2} > c_{S1} > d_{S1}$. However, as weight $\gamma$ increases it is possible for the short-lived workers to consume in the first period more than the long-lived workers in the safe occupation, and also more than the long-lived workers in their occupation.

In Table 4 the short-lived worker has the largest first-period consumption when $\gamma = 2/3$. We also show that increasing the social weight on short-lived individuals, in this case type-$S1$ ones, implies that type-$L1$ individuals are made better off and type-$L2$ worse off when compared with the case in which all individuals attract the same weight. Long-lived workers in the harsh occupation benefit from being mixed with short-lived ones, and they benefit more when the social weight on short-lived individuals increases. This is so despite the fact that the weight directly placed on long-lived individuals in the social objective decreases when the planner tries to correct for the implicit bias towards long-lived individuals that the unweighted utilitarian social objective entails. The same effect is in fact present in the more general case with four types in Table 3: when the proportion of short-lived workers in the harsh occupation is sufficiently large the long-lived workers in the harsh occupation are made better-off by an increase in the social weight of short-lived individuals.

If all workers in the harsh occupation are short-lived the only relevant SSC is the one that relates long- and short-lived individuals in the safe occupation. For the long-lived individuals, who work all in the safe occupation:

$$u'(c_{L2}) = u'(d_{L2}) = \frac{v'(z_{L2};\ell_L)}{w} = \frac{\mu}{1-\gamma+\frac{\lambda_2}{n_2(1-p_2)}}. \tag{21}$$

For workers in the harsh occupation, which can all be identified as short-lived, we have:

$$u'(c_{S1}) = u'(d_{S1}) = \frac{v'(z_{L1};\ell_L)}{w} = \frac{\mu}{\gamma}, \tag{22}$$

which implies non-distortion in this case since there are no long-lived workers in the harsh occupation who can mimic them:

$$\frac{u'(c_{S1})}{u'(d_{S1})} = 1 \text{ and } \frac{v'(z_{S1};\ell_L)}{u'(d_{S1})} = w. \tag{23}$$

For short-lived workers in the safe occupation we have:

$$u'(c_{S2}) = \frac{\mu}{\gamma-\frac{\lambda_2}{n_2p_2}},\ u'(d_{S2}) = \frac{\mu}{\gamma-\frac{\lambda_2}{n_2p_2}\frac{\ell_L}{\ell_S}} \text{ and } v'(z_{S2};\ell_S) = \frac{1}{\gamma}\left(\mu w + \frac{\lambda_2}{n_2p_2}v'(z_{S2};\ell_L)\right), \tag{24}$$

which implies distortions at both margins.

It follows that $c_{S1} = d_{S1} > c_{S2} > d_{S2}$, which together with $z_{S1} < z_{S2}$, implies $U_{S1} > U_{S2}$. Hence, we obtain the usual horizontal inequity with short-lived workers in the safe occupation achieving a lower utility level than the short-lived workers in the harsh occupation. For equal weights $c_{L2} = d_{S2} > c_{S1} = d_{S1} > c_{S2} > d_{S2}$. However, as weight $\gamma$ increases it is possible that $c_{S1} > c_{L2}$ and even that $c_{S2} > c_{L2}$. This is for instance the case with $\gamma = 2/3$ in Table 5. The second-period consumption of the short-lived workers in the safe occupation is larger than that of the long-lived workers in the same occupation, but their second-period consumption is much smaller ($d_{S2} < d_{L2}$) due to a large marginal tax on the savings of $S2$.

It is worth highlighting that the short-lived workers in the safe occupation are made worse-off, and the short-lived workers in the harsh occupation are made better off, as $\gamma$ increases. The gap between their utility levels, and hence the horizontal inequity, becomes more pronounced. Even if type-$S2$ workers receive a larger social weight they suffer from being tangled with long-lived workers in their occupation (i.e. type-$L2$). The weight correction does not benefit this type of short-lived individuals: in fact, type-$S2$ workers would be better off if no weight correction was employed. The combination of tagging and increased social weight on short-lived individuals harms the short-lived workers in the safe occupation.

The last example suggests that tampering with the social weight $\gamma$ placed on short-lived individuals is a rude instrument to correct for the implicit bias towards long-lived in the unweighted utilitarian social objective. This is particularly striking in the tagging solution with three types in which all individuals in the harsh occupation are short-lived. The short-lived workers in the safe occupation that cannot be immediately recognised as such are harmed by the larger social weight that is in principle designed to favour them. It makes sense at this point to explore the alternative maximin solution that ensures that the short-lived workers in the safe occupation are not made worse off than their counterparts in the harsh occupation.

#### 4.2.2 Maximin

The Lagrangian associated with the maximin objective is:

$$\begin{aligned}
&\pounds = u(c_{S1}) + \ell_S u(d_{S1}) - v(z_{S1}; \ell_S) \\
&+\mu \sum_{j=1,2} n_j \left\{ (1-p_j) \left[ (1+z_{Lj})\, w - c_{Lj} - \ell_L d_{Lj} \right] + p_j \left[ (1+z_{Sj})\, w - c_{Sj} - \ell_S d_{Sj} \right] \right\} \\
&+\lambda_1 \left[ u(c_{L1}) + \ell_L u(d_{L1}) - v(z_{L1}; \ell_L) - u(c_{S1}) - D u(d_{S1}) + v(z_{S1}; \ell_L) \right] \\
&+\lambda_2 \left[ u(c_{L2}) + \ell_L u(d_{L2}) - v(z_{L2}; \ell_L) - u(c_{S1}) - \ell_L u(d_{S2}) + v(z_{S2}; \ell_L) \right] \\
&+\delta \left[ u(c_{S2}) + \ell_S u(d_{S2}) - v(z_{S2}; \ell_S) - u(c_{S1}) - \ell_S u(d_{S1}) + v(z_{S1}; \ell_S) \right].
\end{aligned}$$

where $\gamma$ is the Lagrangian multiplier associated with the constraint that ensures that the short-lived individuals in the safe occupation are not made worse than the short-lived individuals in the harsh occupation.

Rearranging the FOCs for types $Lj$ $(j = 1, 2)$, we obtain:

$$u'(c_{Lj}) = u'(d_{Lj}) = \frac{v'(z_{Lj}; \ell_L)}{w} = \frac{n_j (1-p_j)\, \mu}{\lambda_j}, \tag{25}$$

which implies non-distortion on long-lived workers in both occupations:

$$\frac{u'(c_{Lj})}{u'(d_{Lj})} = 1 \text{ and } \frac{v'(z_{Lj}; \ell_L)}{u'(d_{Lj})} = w. \tag{26}$$

As mentioned before, it does not mean however that they receive the same bundle $(c_{Lj}, d_{Lj}, z_{Lj})$. The particular bundle that each long-lived individual in each occupation receives depends on the proportions of long- and short- lived individuals in each occupation.

Rearranging the FOCs we obtain for the short-lived worker in the harsh occupation $S1$:

$$u'(c_{S1}) = \frac{n_1 p_1 \mu}{1-\delta-\lambda_1}, \ u'(d_{S1}) = \frac{n_1 p_1 \mu}{1-\delta-\lambda_1 \frac{\ell_L}{\ell_S}} \text{ and } v'(z_{S1};\ell_S) = \frac{n_1 p_1 \mu w + \lambda_1 v'(z_{S1};\ell_L)}{1-\delta}, \tag{27}$$

and for the short-lived worker in the safe occupation $S2$:

$$u'(c_{S2}) = \frac{n_2 p_2 \mu}{\delta-\lambda_2}, \ u'(d_{S2}) = \frac{n_2 p_2 \mu}{\delta-\lambda_2 \frac{\ell_L}{\ell_S}} \text{ and } v'(z_{S2};\ell_S) = \frac{n_2 p_2 \mu w + \lambda_2 v'(z_{S2};\ell_L)}{\delta}. \tag{28}$$

Short-lived individuals are distorted at both margins - prolonging activity and savings:

$$\frac{u'(c_{S1})}{u'(d_{S1})} < 1 \text{ and } \frac{v'(z_{S1};\ell_S)}{u'(d_{S1})} = w + \frac{\lambda_1}{1-\delta}\left(\frac{v'(z_{S1};\ell_L)}{u'(d_{S1})} - \frac{\ell_L}{\ell_S}w\right) < w, \tag{29}$$

$$\frac{u'(c_{S2})}{u'(d_{S2})} < 1 \text{ and } \frac{v'(z_{S2};\ell_S)}{u'(d_{S2})} = w + \frac{\lambda_2}{\delta}\left(\frac{v'(z_{S2};\ell_L)}{u'(d_{S2})} - \frac{\ell_L}{\ell_S}w\right) < w. \tag{30}$$

As before, the extent of the distortion on each short-lived individual depends on the proportion of short- and long-lived individuals in each occupation, and also on $\delta$. It can be shown that $\delta > 0$ so that the constraint that links the two short-lived types is binding. This does not mean that they receive the same bundle but that they achieve the same utility level:

$$u(c_{S2}) + \ell_S u(d_{S2}) - v(z_{S2};\ell_S) = u(c_{S1}) + \ell_S u(d_{S1}) - v(z_{S1};\ell_S).$$

In the numerical examples provided in Table 6 the short-lived workers in the harsh occupation retire later. This result is similar to that obtained by Pestieau and Racionero (2013) for the health status case. However, in the present case there is an additional distortion at the margin between first- and second-period consumption: the short-lived workers in the safe occupation consume more in the first period and less in the second period than their counterparts in the harsh occupation. Both long-lived types smooth consumption between periods, with those in the harsh occupation consuming more and retiring earlier, hence achieving a higher utility, than their counterparts in the safe occupation. Short-lived workers in the safe occupation consume the most in the first period, consume the least in the second period and retire the earliest. The differences are more pronounced when the longevity distribution across occupations differs markedly (i.e. when occupation 1 is significantly harsher). The distortions imposed on short-lived workers in the harsh occupation decrease as occupation 1 becomes harsher, while the distortions imposed on short-lived workers in the safe occupation increase. The marginal tax rate on savings becomes so large that the gap between first- and second period consumption becomes very large and the second-period consumption $d_{S2}$ quite small. The marginal tax rate on prolonging activity becomes so large that the individual retires quite young. To sum up, the short-lived worker in the safe occupation is induced to overconsume in the first period, underconsume in the second period and retire very early, when compared with the solutions for the other types, and with the solutions for this particular type for other information and policy settings.

# 5 Conclusions

In this paper we have explored whether special pension provisions, such as early retirement, should be offered to workers in occupations characterized by lower average longevity. We addressed this issue in an optimal non-linear tax setting where individuals differ in longevity and occupation, longevity is private information but imperfectly correlated with occupation, which can be observed and used as a tag. We adopted a weighted utilitarian social objective to partially redress the implicit bias towards long-lived individuals that the unweighted utilitarian objective entails and explored the implications of letting the weights vary. We compared two second-best solutions - a common social security policy across occupations and tagging by occupations - and showed that there is a case for differentiating the social security policy by occupation. We showed that the second-best solution is characterized by non-distortion on long-lived workers and distortions at both margins - prolonging activity and savings - on short-lived ones. When tagging is allowed the particular bundles allocated to each type, and the extent of the distortions on each short-lived type, depend on the proportions of short- and long-lived workers in each occupation.

We performed numerical simulations to illustrate how the social security policies, and the utilities achieved by individuals, differ by occupation. Both short- and long-lived workers in the harsh occupations are made better off, while those in the safe occupation are made worse-off, by tagging. Interestingly, an increase in the social weight of short-lived individuals can make long-lived workers in the harsh occupation better off. We showed examples of such an outcome in the three-types case where all workers in the safe occupation are long-lived, and in the four-types case when the proportion of short-lived individuals in the harsh occupation is sufficiently large. The long-lived workers in the harsh occupation benefit from being mixed with short-lived ones even if, as long-lived individuals, they attract a lower weight in the social objective. We also showed that an increase in the social weight placed on short-lived individuals can make the short-lived workers in the safe occupation worse off. We showed examples of such an outcome in the three-types case when all workers in the harsh occupation are short-lived, and in the four-types case when the proportion of short-lived workers in the safe occupation is sufficiently small.

The examples discussed above suggest that increasing the social weight of short-lived individuals is a rude instrument to correct for the implicit redistribution towards long-lived ones that results with the unweighted utilitarian social objective. We explored also the implications of adopting a maximin criterion instead, which ensures horizontal equity among short-lived workers. The short-lived types achieve the same utility level but their treatments differ. In our examples the short-lived workers in the safe occupation consume the most in the first period, consume the least in the second period and retire the earliest, with large distortions at both margins - prolonging activity and savings. The differences are more pronounced when the longevity distribution across occupations differs markedly (i.e. when occupation 1 is significantly harsher). As occupation 1 becomes harsher the distortions at both margins on short-lived workers in the harsh occupation become smaller while the distortions at both margins on short-lived workers in the safe occupation can become quite large.

It is worth stressing the distinction between the scheme our results suggest and the special pension provisions in place in many OECD countries, which typically imply the same treatment for all workers in a given occupation deemed harsh. Our results suggest that special pension policies should be sufficiently flexible to separate the lucky from the unlucky within each occupation when both short- and long-lived workers coexist in both occupations. Because the distribution of short- and long-lived workers differs by occupation, tagging by occupation still implies horizontal inequities among individuals essentially identical (workers with the same life expectancy in different occupations). We partially address this problem by requiring that the short-lived workers in the safe occupation are not made worse-off than their counterparts in the harsh occupation.

We have abstracted from political economy considerations. Granting special pension provisions to certain occupations is not without cost when political economy aspects are considered: workers who are well organized are more likely to obtain special provisions and, in a dynamic setting, it may be difficult to withdraw special treatments when formerly harsh occupations turn to be less demanding. The case of railway workers is a canonical example of such evolution. We argue that the pension schemes should be allowed to differ when objective data reflects longevity differences by occupation, and be flexible enough to accommodate changes in circumstances (e.g. if an occupation once deemed harsh becomes safer). Indeed our approach highlights the need to better understand the relationship between occupation and longevity.

We assumed homogeneous wages across occupations to focus on the insurance role of the pension schemes. We have briefly discussed the implications of allowing wages to differ across occupations: both redistribution and insurance aspects play then a role, in the same or opposite directions depending on whether the harsher occupation is characterized by a lower or a higher wage. We have however not formally incorporated endogenous occupational choice in this paper. There are in reality complex interrelations between the innate ability, the quality of occupation and the earnings of workers that would require a more ambitious model to capture them. We think that the present framework can serve as a basis on which to build models of increasing complexity to analyse the implications of endogenous occupational choice.

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# A Numerical illustration

The functional form we employ for the numerical simulation is:

$$U_{ij} = u(c_{ij}) + \ell_i u(d_{ij}) - v(z_{ij}; \ell_i) = \ln c_{ij} + \ell_i \ln d_{ij} - \frac{1}{\alpha \ell_i} \frac{z_{ij}^{\epsilon}}{\epsilon}.$$

We use $w = 100$ and $\varepsilon = 2$, as well as $\ell_L = 1$ and $\ell_S = 2/3$. We also use $\alpha = 0.4$.[6] We assume $n_1 = n_2 = 1/2$ (i.e., the proportion of individuals working in each of the two occupations is the same) and focus on the role of varying the proportions $p_i$. We start from the benchmark case where $p_1 = p_2 = 1/2$ and explore subsequently the relevant cases where $p_1 > p_2$, when occupation 1 is effectively harsher than occupation 2, keeping the overall proportion of short-lived individuals in the society however constant, so that the role of the different ratios of short- to long-lived workers by occupation is isolated from the role of the overall number of short-lived individuals in the society.

The longevity parameter values above are chosen to fit life expectancy tables: in particular, life expectancy at 50 ($LE_{50}$) for males in Table 2 in Cambois et al. (2011). By setting the length of a period to be about 30 years and considering 55 the threshold between the first period and the

[6] This value ensures that individuals do enjoy some positive time at retirement.

| | Laissez-faire | | FB($\gamma = 0.5$) | | FB($\gamma = 2/3$) | |
|---|---|---|---|---|---|---|
| Types | $S$ | $L$ | $S$ | $L$ | $S$ | $L$ |
| $c$ | 80 | 76.24 | 77.89 | 77.89 | 111.03 | 55.51 |
| $d$ | 80 | 76.24 | 77.89 | 77.89 | 111.03 | 55.51 |
| $z/\ell$ | 0.500 | 0.525 | 0.514 | 0.514 | 0.360 | 0.721 |
| $R$ | 61.67 | 70.74 | 61.85 | 70.41 | 59.80 | 76.62 |
| $U$ | 7.095 | 8.324 | 7.039 | 8.381 | 7.741 | 7.384 |

Table 1: Laissez-faire and first-best for different weights

second period (it could correspond to the minimum legal age for retirement), the average $LE_{50}$ in a population with half of the individuals of each type is 80 (consistent with a $LE_{50}$ average of 29 in their Table 2). A distribution of $(p_1, p_2) = (0.8, 0.2)$ corresponds to an average longevity of 77.5 and 82.5 in occupations 1 and 2, respectively, a 5-year gap that is consistent with the $LE_{50}$ gap between manual workers and highly qualified occupations in their Table 2.

We include in Table 1 the results for the laissez-faire and first-best for different weights, $\gamma = 0.5$ which corresponds to equal weights and $\gamma = 2/3$, which implies a larger weight is attached to short-lived individuals in the utilitarian social objective.[7] $z/\ell$ represents the proportion of the second period (of different length) that individuals works. We also include for easier interpretation the retirement age, represented by $R$, that would correspond to the normalization mentioned above (a period of 30 years for the long-lived and 20 years for the short-lived that starts at 55).

We include in Table 2 the second-best without tagging (i.e. when the planner is not allowed to differentiate the social security policy by occupation) for different weights.[8]

We include in Table 3 the second-best with tagging (i.e. when the planner is allowed to differentiate the social security policy by occupation). We do so for two weights - $\gamma = 0.5$ and $\gamma = 2/3$- to discuss the implications of increasing the weight, and for two different distributions of long-lived and short-lived workers across the occupations - $(p_1, p_2) = (0.6, 0.4)$ and $(p_1, p_2) = (0.8, 0.2)$ - to explore the implications of more marked differences in longevity across occupations.

We present in Table 4 the numerical results for the three-types society in which all workers in

[7] It is possible to find the weight $\gamma$ for which $U_S = U_L$. For this particular combination of parameters such weight is slightly below 2/3.

[8] In the tables $T'$ stands for the marginal tax rate on earnings from prolonging activity to enable relatively straight-forward comparison, in terms of magnitude, with traditional optimal income taxes.

| $\gamma$ | 0.5 | | 2/3 | | Maximin | |
|---|---|---|---|---|---|---|
| Types | $S$ | $L$ | $S$ | $L$ | $S$ | $L$ |
| $c$ | 75.03 | 80.37 | 78.68 | 79.32 | 88.71 | 76.62 |
| $d$ | 73.70 | 80.37 | 65.35 | 79.32 | 50.40 | 76.62 |
| $z/\ell$ | 0.527 | 0.498 | 0.457 | 0.504 | 0.350 | 0.522 |
| $R$ | 62.03 | 69.93 | 61.09 | 70.13 | 59.67 | 70.66 |
| $t'$ | 0.018 | 0 | 0.170 | 0 | 0.432 | 0 |
| $T'$ | 0.029 | 0 | 0.254 | 0 | 0.559 | 0 |
| $U$ | 6.953 | 8.464 | 6.978 | 8.429 | 6.996 | 8.337 |

Table 2: Common social security policy second-best benchmark: different weights

| $\gamma = 0.5$ | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $(p_1, p_2)$ | $(0.6, 0.4)$ | | | | $(0.8, 0.2)$ | | | |
| Types | $S1$ | $L1$ | $S2$ | $L2$ | $S1$ | $L1$ | $S2$ | $L2$ |
| $c$ | 75.55 | 80.95 | 74.54 | 79.82 | 76.66 | 82.18 | 73.63 | 78.80 |
| $d$ | 74.47 | 80.95 | 72.95 | 79.82 | 76.11 | 82.18 | 71.57 | 78.80 |
| $z/\ell$ | 0.524 | 0.494 | 0.529 | 0.501 | 0.519 | 0.487 | 0.533 | 0.508 |
| $R$ | 61.99 | 69.83 | 62.06 | 70.03 | 61.92 | 69.60 | 62.11 | 70.23 |
| $t'$ | 0.014 | 0 | 0.021 | 0 | 0.007 | 0 | 0.028 | 0 |
| $T'$ | 0.024 | 0 | 0.035 | 0 | 0.012 | 0 | 0.046 | 0 |
| $U$ | 6.969 | 8.482 | 6.938 | 8.446 | 7.003 | 8.522 | 6.909 | 8.412 |
| $\gamma = 2/3$ | | | | | | | | |
| $(p_1, p_2)$ | $(0.6, 0.4)$ | | | | $(0.8, 0.2)$ | | | |
| Types | $S1$ | $L1$ | $S2$ | $L2$ | $S1$ | $L1$ | $S2$ | $L2$ |
| $c$ | 83.92 | 85.21 | 73.87 | 73.89 | 96.02 | 98.72 | 65.42 | 64.12 |
| $d$ | 73.11 | 85.21 | 58.04 | 73.89 | 90.39 | 98.72 | 44.48 | 64.12 |
| $z/\ell$ | 0.439 | 0.469 | 0.474 | 0.541 | 0.401 | 0.405 | 0.504 | 0.624 |
| $R$ | 60.85 | 69.08 | 61.32 | 71.24 | 60.35 | 67.16 | 61.72 | 73.72 |
| $t'$ | 0.129 | 0 | 0.214 | 0 | 0.059 | 0 | 0.320 | 0 |
| $T'$ | 0.198 | 0 | 0.313 | 0 | 0.094 | 0 | 0.440 | 0 |
| $U$ | 7.131 | 8.615 | 6.823 | 8.239 | 7.835 | 8.979 | 6.499 | 7.433 |

Table 3: Tagging by occupation: different distributions and different weights

| | $\gamma = 0.5$ | | | | | $\gamma = 2/3$ | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Tag | No | | Yes | | | No | | Yes | | |
| Types | $S$ | $L$ | $S1$ | $L1$ | $L2$ | $S$ | $L$ | $S1$ | $L1$ | $L2$ |
| $c$ | 72.95 | 78.19 | 74.24 | 79.61 | 76.92 | 80.62 | 77.28 | 96.08 | 94.60 | 63.56 |
| $d$ | 70.99 | 78.19 | 72.89 | 79.61 | 76.92 | 58.43 | 77.28 | 80.56 | 94.60 | 63.56 |
| $z/\ell$ | 0.539 | 0.512 | 0.532 | 0.502 | 0.520 | 0.419 | 0.518 | 0.376 | 0.423 | 0.629 |
| $R$ | 62.18 | 70.35 | 62.10 | 70.07 | 70.60 | 60.59 | 70.53 | 60.01 | 67.69 | 73.88 |
| $t'$ | 0.027 | 0 | 0.018 | 0 | 0 | 0.275 | 0 | 0.162 | 0 | 0 |
| $T'$ | 0.044 | 0 | 0.030 | 0 | 0 | 0.388 | 0 | 0.243 | 0 | 0 |
| $U$ | 6.890 | 8.391 | 6.930 | 8.439 | 8.348 | 6.955 | 8.360 | 7.809 | 8.876 | 7.373 |

Table 4: Only long-lived workers in safe occupation, without and with tagging, different weights

| | $\gamma = 0.5$ | | | | | $\gamma = 2/3$ | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Tag | No | | Yes | | | No | | Yes | | |
| Types | $S$ | $L$ | $S1$ | $S2$ | $L2$ | $S$ | $L$ | $S1$ | $S2$ | $L2$ |
| $c$ | 77.37 | 82.81 | 78.78 | 76.14 | 81.42 | 78.67 | 82.12 | 91.76 | 67.78 | 69.86 |
| $d$ | 76.69 | 82.81 | 78.78 | 74.81 | 81.42 | 72.56 | 82.12 | 91.76 | 55.79 | 69.86 |
| $z/\ell$ | 0.514 | 0.483 | 0.017 | 0.519 | 0.491 | 0.483 | 0.487 | 0.436 | 0.528 | 0.573 |
| $R$ | 61.85 | 69.49 | 61.77 | 61.93 | 69.74 | 61.45 | 69.61 | 60.81 | 62.04 | 72.18 |
| $t'$ | 0.009 | 0 | 0 | 0.017 | 0 | 0.078 | 0 | 0 | 0.177 | 0 |
| $T'$ | 0.015 | 0 | 0 | 0.029 | 0 | 0.123 | 0 | 0 | 0.264 | 0 |
| $U$ | 7.022 | 8.542 | 7.063 | 6.984 | 8.498 | 7.027 | 8.520 | 7.374 | 6.665 | 8.083 |

Table 5: Only short-lived workers in harsh occupation, without and with tagging, different weights

the safe occupation are long-lived (i.e. $p_2 = 0$) for different weights - $\gamma = 0.5$ and $\gamma = 2/3$ - and we also compare the tagging with the no-tagging solution. We present in Table 5 the numerical results for the three-types society in which all workers in the harsh occupation are short-lived (i.e. $p_1 = 1$) for different weights - $\gamma = 0.5$ and $\gamma = 2/3$ - and we also compare the tagging with the no-tagging solution.

We present in Table 6 the solution with the maximin criterion for two different distributions of long-lived and short-lived workers across the occupations - $(p_1, p_2) = (0.6, 0.4)$ and $(p_1, p_2) = (0.8, 0.2)$ - with the harsh occupation being more so for the latter.

We have assumed throughout the paper that wages are equal across occupations. We have done so to focus on the insurance aspect of the pension schemes and abstract from the standard redistribution role associated with heterogeneous wages. We illustrate in Table 7 how the results

| | $(p_1, p_2) = (0.6, 0.4)$ | | | | $(p_1, p_2) = (0.8, 0.2)$ | | | |
|---|---|---|---|---|---|---|---|---|
| Types | $S1$ | $L1$ | $S2$ | $L2$ | $S1$ | $L1$ | $S2$ | $L2$ |
| $c$ | 83.83 | 78.38 | 97.99 | 74.79 | 81.13 | 82.79 | 159.78 | 69.68 |
| $d$ | 57.71 | 78.38 | 41.90 | 74.79 | 70.78 | 82.79 | 20.41 | 69.68 |
| $z/\ell$ | 0.395 | 0.510 | 0.295 | 0.535 | 0.454 | 0.483 | 0.158 | 0.574 |
| $R$ | 60.27 | 70.31 | 58.94 | 71.05 | 61.06 | 69.49 | 57.11 | 72.22 |
| $t'$ | 0.312 | 0 | 0.572 | 0 | 0.128 | 0 | 0.872 | 0 |
| $T'$ | 0.430 | 0 | 0.691 | 0 | 0.196 | 0 | 0.919 | 0 |
| $U$ | 7.002 | 8.397 | 7.002 | 8.272 | 7.064 | 8.541 | 7.064 | 8.076 |

Table 6: Maximin: different distributions

change when wages differ across occupations under two different scenarios: when the wage is higher in the harsh occupation - in the example $(w_1, w_2) = (125, 75)$ - and when alternatively the wage is higher in the safe occupation - in the example $(w_1, w_2) = (75, 125)$. The latter corresponds better to the empirical evidence in Cambois et al. (2011) that workers in highly-qualified occupations are more likely to live longer. In this case the effects already present in Table 3 get reinforced because the insurance and redistribution roles reinforce each other.

| $(w_1, w_2) = (125, 75)$ | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $(p_1, p_2)$ | $(0.6, 0.4)$ | | | | $(0.8, 0.2)$ | | | |
| Types | $S1$ | $L1$ | $S2$ | $L2$ | $S1$ | $L1$ | $S2$ | $L2$ |
| $c$ | 75.35 | 83.04 | 76.53 | 79.69 | 76.21 | 84.06 | 75.32 | 78.40 |
| $d$ | 73.81 | 83.04 | 75.59 | 79.69 | 75.43 | 84.06 | 74.08 | 78.40 |
| $z/\ell$ | 0.655 | 0.602 | 0.389 | 0.376 | 0.652 | 0.595 | 0.394 | 0.383 |
| $R$ | 63.73 | 73.06 | 60.18 | 66.29 | 63.69 | 72.84 | 60.25 | 66.48 |
| $t'$ | 0.020 | 0 | 0.012 | 0 | 0.010 | 0 | 0.016 | 0 |
| $T'$ | 0.034 | 0 | 0.020 | 0 | 0.017 | 0 | 0.027 | 0 |
| $U$ | 6.833 | 8.385 | 7.095 | 8.579 | 6.862 | 8.421 | 7.062 | 8.541 |
| $(w_1, w_2) = (75, 125)$ | | | | | | | | |
| $(p_1, p_2)$ | $(0.6, 0.4)$ | | | | $(0.8, 0.2)$ | | | |
| Types | $S1$ | $L1$ | $S2$ | $L2$ | $S1$ | $L1$ | $S2$ | $L2$ |
| $c$ | 77.84 | 81.07 | 74.61 | 82.15 | 79.24 | 82.55 | 73.99 | 81.38 |
| $d$ | 77.20 | 81.07 | 72.35 | 82.15 | 78.91 | 82.55 | 71.03 | 81.38 |
| $z/\ell$ | 0.383 | 0.370 | 0.657 | 0.609 | 0.378 | 0.363 | 0.658 | 0.614 |
| $R$ | 60.11 | 66.10 | 63.76 | 73.26 | 60.03 | 65.90 | 63.78 | 73.43 |
| $t'$ | 0.008 | 0 | 0.030 | 0 | 0.004 | 0 | 0.040 | 0 |
| $T'$ | 0.014 | 0 | 0.050 | 0 | 0.007 | 0 | 0.065 | 0 |
| $U$ | 7.130 | 8.619 | 6.807 | 8.354 | 7.166 | 8.662 | 6.785 | 8.326 |

Table 7: Tagging by occupation: different wages and different distributions, equal weights