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COPING WITH DEMOGRAPHIC CHANGE: MACROECONOMIC PERFORMANCE AND WELFARE INEQUALITY EFFECTS OF PUBLIC PENSION REFORM

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Coping with demographic change: macroeconomic performance and welfare inequality effects of public pension reform

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Abstract

Demographic change forces governments in all OECD countries to reform the public pension system. Increased sensitivity to rising inequality in society has made the challenge for policy makers only greater. In this paper we evaluate alternative reform scenarios. We employ an overlapping generations model for an open economy with endogenous hours worked, human and physical capital, output, and welfare. Within each generation we distinguish individuals with high, medium or low ability to build human capital. Frequently adopted reforms in many countries such as an increase of the normal retirement age or a reduction in the pension benefit replacement rate can guarantee the financial sustainability of the system, but they fail when the objective is also to improve macroeconomic performance and aggregate welfare without raising intergenerational or intragenerational welfare inequality. Our results prefer a reform which combines an increase of the retirement age with an intelligent design of the linkage between the pension benefit and earlier labour earnings. First, this design conditions pension benefits on past individual labour income, with a high weight on labour income earned when older and a low weight on labour income earned when young. Second, to avoid rising welfare inequality this linkage is complemented by a strong rise in the benefit replacement rate for low ability individuals (and a reduction for high ability individuals).

JEL classification: E6, H55, J22, J26

Keywords: demographic change, population ageing, pension reform, retirement age, heterogeneous abilities, inequality, overlapping generations

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1 Introduction

In light of increasing life expectancy, low fertility rates, and rising financial pressure on social security budgets, many countries have introduced (or consider) reforms of their public pension systems. Many of these reforms impose parametric adjustments to the existing pay-as-you-go (PAYG) scheme. Among the most frequent adjustments are an extension of the normal or statutory retirement age and a reduction in pension benefits (Beetsma et al., 2017). On average over all EU28 countries, the normal retirement age for men who entered the labour market at age 20 in 2016 will be 2.1 years higher than for men who retired in 2016. For women the increase will be 2.6 years (OECD, 2017). Undoubtedly, in the coming years further increases will be decided.

Although raising the retirement age and reducing benefits will directly reduce expenditures and improve the financial sustainability of public pension arrangements, the question arises if these frequent reforms also dominate other reforms when it comes to promoting macroeconomic performance and welfare, and to avoiding inequality. Maybe other reforms are possible with equally good budgetary effects, but better results regarding employment and all-inclusive per capita growth and welfare? The question is important. Downward pressure on per capita income due to demographic changes, underemployment of older and low educated people, as well as increasing sensitivity in society to the problem of inequality, have made the challenge for policy makers only larger. Not only budgetary outcomes, but also productive efficiency and - especially - equity demand attention.

This paper addresses this research question. We compare the effects of a single increase of the retirement age and a single reduction of the benefit replacement rate, generating equal budgetary savings, with the effects of more comprehensive reforms also including (smart) changes in the earnings-related linkage in a PAYG system. The government in this paper can impose a strong, a weak or no linkage between the pension benefit and past individual labour earnings (and contributions). When there is a linkage, it can give different weights in the pension assessment base to labour income earned at different ages, i.e. the pension accrual rate can change by age. If the government prefers no direct link to individual earnings, it can guarantee a minimum pension to those who would otherwise run the risk of old age poverty. For earnings-related pension systems, the government can choose the level of the replacement rate. This can be different for individuals with different market income (ability). Otherwise, it can choose the level and/or the specific type of the minimum pension[1].

To approach the question, we employ a 28 period overlapping generations model for an open economy. We developed this model in Devriendt and Heylen (2017) and found it able to replicate the evolution since 1960 of key macro variables in Belgium. The model explains hours worked by the active generations at different age, (tertiary) education and human capital accumulation by the young, physical capital formation by firms, aggregate output and income, and welfare,

[1]Pensions reforms that aim at financial balance by raising contribution rates or taxes are not the focus of this paper. Many researchers have shown that these reforms are inferior in their long-run effects on employment, growth and welfare (e.g. Kotlikoff et al., 2007; Kitao, 2014).

within one coherent framework. The model also incorporates heterogeneity in the innate ability of individuals as the main source of inequality. Individuals with higher innate ability enter the model with more human capital. They are also more productive in building additional human capital when they allocate time to education. Modelling endogenous behaviour and behavioural reactions will be key for us to quantify the macroeconomic repercussions and the welfare effects of pension reforms. Furthermore, introducing differences in ability will allow us to monitor also inequality between individuals with high versus low human capital and earnings capacity.

Our main findings are as follows. Public pension reforms involving an increase of the normal retirement age or a reduction in the pension benefit replacement rate can guarantee the financial sustainability of the system, but they fail when the objective is also to improve macroeconomic performance without raising intergenerational or intragenerational welfare inequality. A reduction of the replacement rate to restore the financial balance of the public pension system fails on both criteria. An increase of the retirement age promotes long-run macroeconomic performance, but will create more welfare inequality. The different capacities of high and low ability individuals to respond to an increase in the retirement age by building more human capital, is a key element behind rising inequality. Our results prefer a more comprehensive reform which supplements an increase of the retirement age with an intelligent adjustment of the linkage between the pension benefit and earlier labour earnings. This adjustment maintains a tight link between the pension benefit and past individual labour income, but with a high weight on labour income earned when older and a low weight on labour income earned when young. Furthermore, to avoid rising welfare inequality this linkage should be complemented by a strong rise in the benefit replacement rate for low ability individuals (and a reduction for high ability individuals). Attempts to cope with rising inequality by introducing a minimum pension may also perform well if the level of the minimum pension rewards hours worked over the career. A minimum pension that is unrelated to hours worked is negative for aggregate employment and welfare.

This paper builds on a large existing literature. Many studies have documented how the pension system may affect the incentives of individuals of different ages to work (e.g. Sheshinski, 1978; Sommacal, 2006; Fisher and Keuschnigg, 2010; Jaag et al., 2010; de la Croix et al., 2013). Others have investigated the relationship between the pension system and investment in human capital, as a major determinant of productivity and growth (e.g. Zhang, 1995; Kemnitz and Wigger, 2000). More recently, Ludwig et al. (2012), Buyse et al. (2013, 2017) and Kindermann (2015) made progress by studying pension reform in OLG models where both employment by age and human capital are endogenous. Last but certainly not least, a large literature has demonstrated the major impact of the pension system on inequality and old-age poverty (e.g. von Weizsacker, 1996; Docquier and Paddison, 2003; Sánchez-Romero and Prskawetz, 2017; Etgeton, 2018).

Most directly relevant for our research is work by Fehr (2000), Kotlikoff et al. (2007), Fehr et al. (2012), Imrohoroglu and Kitao (2012), Kitao (2014), and Li (2018). These authors analysed alternative reforms of the pension system aimed at reducing the level of future public pension expenditures and balancing the budget in the context of demographic change (ageing). Among other policy measures, they also studied the effects of an increase of the normal retirement age and a reduction of the benefit level. We make progress compared to these papers in two ways.

First, we model also human capital accumulation as an endogenous variable, and therefore account for the endogeneity of labour productivity and earnings capacity to demographic change and the characteristics of the pension system. The importance of having endogenous human capital for a proper analysis of the aggregate effects and the inequality effects of pension reform is obvious, considering the work of e.g. Cervellati and Sunde (2013), Ludwig et al. (2012) and Kindermann (2015), and the arguments of Kanbur and Stiglitz (2015). Second, in our evaluation of alternative pension reforms we put the issue of (reducing) inequality more at the center. Kitao (2014), Fehr (2000) and Fehr et al. (2012) also report welfare effects of pension reforms for individuals who differ by level of financial wealth or exogenous productivity level. They do not search for a reform, however, that combines financial sustainability and macroeconomic performance and welfare with a reduction of welfare inequality. This is exactly our main contribution. We propose a reform that achieves not only financial and macro performance objectives, but also succeeds in realising this inequality reduction.

The proposal that we develop, as described above, is strongly inspired by Buyse et al. (2017). Their model and analysis, however, neglected demographic change and ageing, and therefore the main source of rising pressure on social security and pension systems. Moreover, they did not study an extension of the retirement age, nor a reduction of pension benefits, and largely neglected dynamic effects induced by pension reform apart from welfare effects.

Many researchers have introduced heterogeneous abilities in OLG models before. Some have done this to study the effects of the pension system on inequality, as one of the dependent variables. The way in which heterogeneity is introduced differs, however. Some authors model individuals with different human capital (or skill) levels when they enter the model (e.g. Fehr, 2000; Sommacal, 2006; Kotlikoff et al., 2007; Fehr et al., 2012). Others introduce individuals with the same initial human capital, but different learning abilities (e.g. Kindermann, 2015), or subject to idiosyncratic productivity shocks during life (e.g. Fehr et al., 2013; Kitao, 2014). In our model in this paper, like in Buyse et al. (2017), individuals with higher (lower) ability have both higher (lower) initial human capital and are more productive in building additional human capital when they allocate time to (tertiary) education. We abstain, however, from shocks to individual human capital and productivity during individuals' life. This set of assumptions may offer the best match to findings by Huggett et al. (2011) and Keane and Wolpin (1997) that heterogeneity in human capital endowment at young age and learning abilities, rather than shocks to human capital, account for most of the variation in lifetime utility. A final important element is the relationship between the human capital of subsequent generations. In this paper, we follow Ludwig et al. (2012) and Kindermann (2015), among others, and assume that individuals' initial human capital is predetermined and generation-invariant. Growth will then be exogenous.

The structure of this paper is as follows. Section 2 sets out our model. We pay particular attention to the theoretical impact of the pension system on individual behaviour. In Section 3 we describe our calibration procedure and the parameterization of the model. Section 4 describes the results of a range of model simulations. We investigate the employment, education, output, financial and welfare effects of various reforms of the pension system. We study effects per generation and per ability group. In Section 5 we perform some additional robustness checks. Section 6 concludes the paper.

2 The model

2.1 Basic setup

We assume an open economy with an exogenous but time-varying world interest rate. Physical capital moves freely across borders. Human capital and labour however are assumed internationally immobile. Time-varying exogenous fertility and survival rates drive demographic change. Twenty-eight generations of individuals coexist. Individuals enter the model at the age of 18. They live at most for 28 periods of 3 years. Within each generation one fraction of the individuals is assumed to have low innate ability, others have medium ability, a third group has high innate ability. Depending on their ability, individuals will enter the model with a different initial human capital endowment and with a different productivity of schooling. Young individuals with high or medium ability will continue education when they enter the model at 18. Individuals with low ability will not. Next to education and endogenous human capital, our model also has endogenous employment. Besides studying (for high and medium ability individuals) everyone optimally allocates time to labour and leisure. The labour market for high and medium ability households is assumed perfectly competitive. The labour market for low ability households is imperfectly competitive. We assume the existence of a union that sets wages for low ability workers. Above market-clearing wages may cause involuntary unemployment. As to output, domestic firms are modelled to employ physical capital and effective labour under constant returns to scale. Technology is assumed to have exogenous growth.

A central part of our model is the public pension system, the specification of which allows us to simulate a great variety of pension reforms. Finally, the government is an important actor in our model also from the side of fiscal policy. It sets tax rates on labour (both on employees and employers), consumption and capital income. It allocates its resources to goods and services, unemployment benefits and pensions (to finance possible deficits in the public pay-as-you-go system). It may also borrow.

Concerning notation, superscript t denotes the time an individual or group of individuals (a generation) enter the model. Subscript j refers to the j-th period of life or, in other terms, the age. It goes from 1 to 28[2]. When a subscript s is used, it denotes one of three levels of innate ability: low (L), medium (M) or high (H). Last but not least, time subscripts t added to aggregate variables indicate historical time.

2.2 Demography

Demographic change in our model is captured by time-varying fertility and survival rates, with the latter determining individuals' expected length of life. Equation (1) expresses the size of the youngest generation at time t relative to the size of the youngest generation at *t-1*, following among others de la Croix et al. (2013). f_t (> 0) is the time-dependent 'fertility' rate in the model.

$$N_1^t = f_t N_1^{t-1} \tag{1}$$

[2]Note that life starts at age 1 and not at age 0. N_3^t for example denotes the total size of the generation that entered the model at time t when this generation is at model age 3. That will be the case in time period $t+2$.

Equation (2) describes the evolution of the size of a specific generation over time. We denote by sr_{j-1}^t (< 1) the probability for each individual of generation t to survive until model age j conditional on reaching age $j-1$. This survival rate is both generation and age-dependent.

$$N_j^t = sr_{j-1}^t N_{j-1}^t, \text{ for } j = 2 - 28 \tag{2}$$

The trajectories of both f_t and sr_j^t are taken as exogenous in our model. Finally, the population consists of low, medium and high ability agents:

$$\begin{aligned} N_j^t &= N_{j,L}^t + N_{j,M}^t + N_{j,H}^t \\ &= (v_L + v_M + v_H) N_j^t \end{aligned} \tag{3}$$

with v_s denoting their respective shares and $\sum_{s=L,M,H} v_s = 1$. Assuming the fertility and survival rates to be equal across ability types, these shares will be constant[3].

In line with our assumption that only physical capital is internationally mobile, we do not model migration in this paper. Our data for the exogenous fertility rate do, however, capture the impact of migration of individuals not older than 20. The data also count the children of migrants when these children reach age 18-20 (model age 1)[4].

2.3 Households

Individuals of the same generation and ability are grouped in households of unitary mass (Merz, 1995; Andolfatto, 1996; Boone and Heylen, 2018). As low ability individuals can be involuntarily unemployed, their household will consist of both a fraction of unemployed (u) and a fraction of employed members ($1-u$). They pool their income, so consumption is equalized across household members. Medium and high ability households have only employed members.

2.3.1 Instantaneous household utility

The instantaneous utility function of a representative high or medium ability household of generation t and age j depends positively on consumption $c_{j,s}^t$ and leisure time $l_{j,s}^t$ (Equation 4). Preferences are logarithmic in consumption and iso-elastic in leisure. The intertemporal elasticity of substitution in leisure is $1/\theta$. Furthermore, γ_j indicates the relative utility value of leisure versus consumption. It may differ by age. The instantaneous utility function of a low ability household of age j is the same except that only the leisure time of the employed fraction of the household $(1 - u_{t+j-1})$ is taken into account (Equation 5). Implicitly, leisure of the unemployed fraction is assumed to be neutral for household utility.

$$u(c_{j,s}^t, l_{j,s}^t) = lnc_{j,s}^t + \gamma_j \frac{(l_{j,s}^t)^{1-\theta}}{1-\theta}, \text{ for } s = H, M \tag{4}$$

$$u(c_{j,L}^t, l_{j,L}^t) = lnc_{j,L}^t + \gamma_j \left(1 - u_{t+j-1}\right) \frac{(l_{j,L}^t)^{1-\theta}}{1-\theta} \tag{5}$$

with $\gamma_j > 0$ and $\theta > 0$ ($\theta \neq 1$).

[3]What we have in mind, is that ability reflects individuals' IQ, the level and distribution of which are seen as constant. The assumption of constant ability levels and constant shares v_s does not exclude, however, that over time the average skill level of the population increases. This is possible in our model when the individuals of medium or high ability choose to study more and accumulate more human capital than earlier generations.

[4]See Appendix A.1.

2.3.2 Expected lifetime utility

A household that enters the model at time t maximizes expected lifetime utility described by Equation (6) subject to its budget and time constraints (cf. infra). In this equation β is the discount factor and π_j^t the unconditional probability to survive until age j.

$$U^t = \sum_{j=1}^{28} \beta^{j-1} \pi_j^t u(c_{j,s}^t, l_{j,s}^t) \tag{6}$$

with $0 < \beta < 1$, $\pi_1^t = 1$, $0 < \pi_j^t = \prod_{i=1}^{j-1} sr_i^t < 1$ for $1 < j < 29$, and $\pi_{29}^t = 0$.

2.3.3 Time constraints

Every period, an individual is endowed with one unit of time that can be split into hours worked while employed (n), education (e) and leisure (l) depending on age and innate ability. Equations (7) to (9) describe the age-dependent time constraints for medium and high ability individuals ($s = M, H$). Only in the first 4 periods an individual can spend time in post-secondary education next to working and enjoying leisure. From period 5 until 15, time can be allocated only to labour and leisure. From period and age 16 onwards an agent is eligible for public old-age pensions. Equations (10) and (11) relate to low ability individuals. Since these individuals start working earlier than individuals of medium or high ability, they can also leave the labour market earlier. They receive a public pension from period and age 15 onwards[5]. Unemployed low ability individuals cannot choose hours worked or leisure (for them $n_{j,L}^t = 0$). They only have 'leisure'. As mentioned before, this does not carry positive utility.

$$\text{for } j = 1 - 4\,(age\,18 - 29) \quad : \quad l_{j,s}^t = 1 - n_{j,s}^t - e_{j,s}^t \tag{7}$$

$$\text{for } j = 5 - 15\,(age\,30 - 62) \quad : \quad l_{j,s}^t = 1 - n_{j,s}^t \tag{8}$$

$$\text{for } j = 16 - 28\,(age\,63 - 101) \quad : \quad l_{j,s}^t = 1 \tag{9}$$

$$\text{for } j = 1 - 14\,(age\,18 - 59) \quad : \quad l_{j,L}^t = 1 - n_{j,L}^t \tag{10}$$

$$\text{for } j = 15 - 28\,(age\,60 - 101) \quad : \quad l_{j,L}^t = 1 \tag{11}$$

2.3.4 Budget constraints

Households have varying budget constraints over their life cycle depending on age and innate ability. Equation (12) describes the budget constraint faced by households of high and medium ability during active life (periods 1 to 15).

$$\begin{aligned}(1+\tau_c)c_{j,s}^t + a_{j,s}^t =& (1+r_{t+j-1})(a_{j-1,s}^t + tr_{t+j-1}) + w_{t+j-1}^s \varepsilon_j h_{j,s}^t n_{j,s}^t (1-\tau_{w,j,s}) \\ & - T_{j,s} n_{j,s}^t + z_{t+j-1}, \text{ for } s = H, M\ ,\ j = 1 - 15\end{aligned} \tag{12}$$

Disposable income is used to consume $c_{j,s}^t$ and accumulate non-human wealth. We denote by $a_{j,s}^t$ the stock of wealth held by a type s individual at the end of the j-th period of his life.

[5]This assumption also reflects reality in Belgium (see Devriendt and Heylen, 2017). Until 2013 it was possible to retire and receive public pension benefits at age 60. Moreover, many mainly lower educated workers left the labour market even sooner with unemployment-related benefits.

τ_c is the tax rate applied by the government on consumption goods. When individuals assign a fraction $n^t_{j,s}$ of their time to work, with productive efficiency $\varepsilon_j h^t_{j,s}$, they earn a net labour income of $w^s_{t+j-1}\varepsilon_j h^t_{j,s} n^t_{j,s}(1-\tau_{w,j,s})$. Underlying factors are the real gross wage per unit of effective labour of ability type s (w^s_{t+j-1}), an exogenous parameter linking productivity to age (ε_j), human capital ($h^t_{j,s}$), and the average labour income tax rate ($\tau_{w,j,s}$). The contribution rate cr_1 of workers to the public pension system is included in $\tau_{w,j,s}$. Engaging in work, however, also induces costs related to child care and transportation $T_{j,s}$. Moreover, if the individuals in a household work more days a week and more weeks per year, implying higher n, these costs will rise. This explains why we have $T_{j,s}n^t_{j,s}$ in the budget constraint. One reason for T to depend on ability is for example the use of company cars, which make transportation cheaper typically for higher ability individuals. A reason for T to depend on age is the need (to pay for) for child care at low j, when households have children.

Next to labour income, disposable income consists of interest income earned on assets, $r_{t+j-1}a^t_{j-1,s}$ with r_{t+j-1} the exogenous world real interest rate, and lump-sum transfers received from the government z_{t+j-1}. A final source of income are transfers from accidental bequests tr_{t+j-1} (plus interest). There are no annuity markets in our model. Transfers are uniformly distributed among the population (N_k):

$$tr_k = \frac{1}{N_k}\left[\sum_s \sum_{j=1}^{28}\left(1 - sr^{k-j}_j\right) a^{k-j}_{j,s} N^{k-j}_{j,s}\right]$$

From the eligible pension age $j = 16$ onwards individuals of high and medium ability receive public pension benefits $ppt^t_{j,s}$. Equation (13) presents these individuals' budget constraint.

$$\begin{aligned}(1+\tau_c)c^t_{j,s} + a^t_{j,s} = (1+r_{t+j-1})(a^t_{j-1,s} + tr_{t+j-1}) + ppt^t_{j,s} + z_{t+j-1} \\ \text{for } s = M, H,\ j = 16-28.\end{aligned} \tag{13}$$

The budget constraint of low ability households at working age (Equation 14) looks slightly different. Here, only the employed fraction of the representative household $(1-u_{t+j-1})$ earns a labour income while the unemployed part receives an unemployment benefit related to what they would have earned when employed. The policy parameter b indicates the gross benefit replacement rate.

$$\begin{aligned}(1+\tau_c)c^t_{j,L} + a^t_{j,L} = (1+r_{t+j-1})(a^t_{j-1,L} + tr_{t+j-1}) + bw^L_{t+j-1}\varepsilon_j h^t_{j,L} n^t_{j,L} u_{t+j-1} \\ +w^L_{t+j-1}\varepsilon_j h^t_{j,L} n^t_{j,L}(1-\tau_{w,j,L})\left(1-u_{t+j-1}\right) - T_{j,L}n^t_{j,L}\left(1-u_{t+j-1}\right) + z_{t+j-1} \\ \text{for } j = 1-14.\end{aligned} \tag{14}$$

After retirement (from age $j = 15$ onwards) the budget constraint of low ability households is the same as the one of high or medium ability households.

$$(1+\tau_c)c^t_{j,L} + a^t_{j,L} = (1+r_{t+j-1})(a^t_{j-1,L} + tr_{t+j-1}) + ppt^t_{j,L} + z_{t+j-1}, \text{ for } j = 15-28. \tag{15}$$

All households in our model are born without assets. They also plan to consume all accumulated assets by the end of their life. A final assumption is that retired individuals cannot have negative assets. Algebraically, $a^t_{0,s} = a^t_{28,s} = 0$ and $a^t_{j,s} \geq 0$ for $j > 15$ (for $s = H, M$) or 14 (for $s = L$).

2.4 Human capital production

Individuals enter the model at the age of 18 with a predetermined ability-specific endowment of human capital. In Equation (16), h_0 stands for the initial time-invariant human capital endowment of a high ability individual. Low and medium ability individuals are respectively endowed with lower human capital stocks $\omega_L h_0$ and $\omega_M h_0$ with $0 < \omega_L < \omega_M < \omega_H = 1$.

$$h^t_{1,s} = \omega_s h_0 \tag{16}$$

High and medium ability individuals can engage in higher education to accumulate additional human capital in the first four periods (Equation 17a). ϕ_s is a positive ability-related efficiency parameter reflecting the productivity of schooling, and σ the elasticity of human capital growth with respect to time input. After the first four periods, human capital remains constant (Equation 17b). We assume that learning-by-doing offsets depreciation. Constant human capital, however, doesn't imply constant productive efficiency $h^t_j \varepsilon_j$, as there is still variation in the exogenous age-productivity link ε_j.

$$h^t_{j+1,s} = h^t_{j,s}\left(1 + \phi_s (e^t_{j,s})^\sigma\right) \qquad \text{for } j = 1-4, s = H, M \tag{17a}$$

$$= h^t_{j,s} \qquad \text{for } j \geq 5, s = H, M \tag{17b}$$

with: $0 < \sigma < 1$, $\phi_H, \phi_M > 0$.

Individuals with low innate ability do not study at the tertiary level. Their human capital remains constant at the initial level:

$$h^t_{j+1,L} = h^t_{1,L}. \quad \forall j \tag{18}$$

2.5 The pension system

Our model includes a public pay-as-you-go (PAYG) pension scheme of the defined benefit type that makes pension payments to retirees out of contributions (taxes) paid by current workers and firms. Individuals receive a pension benefit from model age $j = 16$ (for $s = H, M$) or $j = 15$ (for $s = L$) onwards, i.e. respectively actual age 63 or 60. The amount $ppt^t_{j,s}$ they receive at the time of retirement is

$$ppt^t_{16,s} = rr_s \left\{ \sum_{j=1}^{15} p_j w^s_{t+j-1} \varepsilon_j h^t_{j,s} n^t_{j,s} (1 - \tau_{w,j,s}) \prod_{l=j}^{15} wg_{t+l} \right\}, \textit{ for s=H,M} \tag{19a}$$

or

$$ppt^t_{15,L} = rr_L \left\{ \sum_{j=1}^{14} p_j w^L_{t+j-1} \varepsilon_j h^t_{j,L} n^t_{j,L} (1 - \tau_{w,j,L}) \prod_{l=j}^{14} wg_{t+l} \right\} \tag{19b}$$

with $\sum p_j = 1$.

The pension benefit is related to one's own contributions during active life. More precisely, the pensioner receives a fraction of the weighted average of revalued earlier net labour income. In Equation (19), p_j determines the weight of net labour income earned at age j, rr_s is the net replacement rate, which can differ by ability (income), and wg is the period-wise revaluation factor applied to net labour income earned in the past. The pension will rise in the earned wage, the individual's hours of work and his productive efficiency with the latter also increasing in human capital. For retired low ability households the pension amount is very similar, except for the lower eligibility age of 60 (model age 15). Underlying this result, is our assumption that periods of unemployment, as experienced by some household members, are considered equivalent to periods of work. After the initial pension payment, the pension benefit may be revalued to adjust for a changed living standard, so $ppt^t_{j,s}$ then becomes

$$ppt^t_{j,s} = ppt^t_{16,s} \prod_{l=16}^{j-1} pg_{t+l}, \text{ for j>16 and } s{=}H{,}M \tag{20a}$$

or

$$ppt^t_{j,L} = ppt^t_{15,L} \prod_{l=15}^{j-1} pg_{t+l}, \text{ for j>15} \tag{20b}$$

with pg_k the coefficient that revalues the pension benefit of period $k-1$ to k.

The public pension system's budget identity is as follows:

$$\sum_{s=M,H} \sum_{j=16}^{28} N^{t+1-j}_{j,s} ppt^{t+1-j}_{j,s} + \sum_{j=15}^{28} N^{t+1-j}_{j,L} ppt^{t+1-j}_{j,L} =$$

$$cr \sum_{s=M,H} \sum_{j=1}^{15} N^{t+1-j}_{j,s} n^{t+1-j}_{j,s} w^s_t \varepsilon_j h^{t+1-j}_{j,s} + cr \sum_{j=1}^{14} N^{t+1-j}_{j,L} (1-u_t) n^{t+1-j}_{j,L} w^L_t \varepsilon_j h^{t+1-j}_{j,L} + GPP_t \tag{21}$$

with

$$cr = cr_1 + cr_2.$$

The left side of Equation (21) indicates total pension expenditures at time t. As public pensions are organized on a PAYG basis, this amount is financed by a) the working population from taxes on their gross labour income applying contribution rate cr_1 and by b) the firms applying cr_2. In Equations (12) and (14), cr_1 is thus part of the labour tax rate $\tau_{w,j,s}$. Tailored to institutional reality in Belgium, GPP_t denotes the total resources assigned to pension payments by the government to ensure that Equation (21) holds.

2.6 Household optimisation and the role of the pension system

Low ability individuals will choose consumption and labour supply to maximize Equation (6), taking into account their instantaneous utility function in Equation (5), their time and budget constraints in Equations (10), (11), (14) and (15), and the human capital process in Equations (16) and (18). Individuals of medium and high ability will in addition choose the fraction of time they spend in education when young. They optimize Equation (6), subject to Equations (4), (7)-(9), (12)-(13) and (16)-(17). For details on the optimality conditions, we refer to an appendix in Devriendt and Heylen (2017).

Building on our discussion of the pension system in the previous section, and Equation (19) in particular, our focus here is on the strong effects on behaviour in earlier periods of life that the specific organisation of public pension benefits may have. We first discuss these effects for a given way of financing. Both income and substitution effects occur:

- For given contribution rates, a higher replacement rate rr raises the return to working (for all ability groups) and to building human capital (for high and medium ability individuals) in earlier periods. It will encourage individuals to work and to invest in education.

- Changes in the particular weights of the periods that constitute the pension assessment base p_j, may modify these incentive effects. The return to working in a particular period rises in the weight attached to that period. A shift in weight from labour income earned when young to labour income earned when older brings strong incentives to work less when young, and to work more and longer when old. This shift also includes a strong incentive to invest in human capital, due to the reduced opportunity cost of education and the increased return to employed human capital (for given hours worked) at higher age.

- Pension systems that encourage individuals to work more when middle aged or older, also stimulate them to study when young (at least when they have medium or high innate ability). The reason is that an increase in labour supplied during these periods raises the return to education. Following the same logic, also an increase in the normal retirement age will make it more interesting for young individuals to study. Conversely, individuals who invest more in human capital when young will also prefer to work more and longer at higher age. The reason here is that a higher level of human capital raises wages and the return to working.

- Higher replacement rates do not only bring about substitution effects, however. Raising individuals' lifetime consumption possibilities, they also cause adverse income effects on labour supply.

Obviously, for a proper assessment of the effects of pension systems and reforms, it is good also to consider the issue of financing. Maybe tax or contribution rates do not change[6], but of course they can. In this respect, it has been shown in the literature that if an increase of the replacement rate and the future pension benefit is associated with an increase in the tax or contribution rate on labour, the positive effect on labour supply disappears. In most cases, i.e. when the present discounted value of benefits is lower than the value of the contributions, the effect may turn negative (see for example Cigno, 2008; Fisher and Keuschnigg, 2010). The positive effect on education will not disappear, however. A PAYG pension system with earnings-related benefits will always encourage individuals to invest in education when young[7]. The reason is that when the present value of future benefits is lower than the value of the contributions, an implicit tax structure results that has high tax rates on labour income in the first period of active life and lower tax rates towards the end. This subsidizes human capital formation (see also Kindermann, 2015). Raising individuals' future wages, a higher level of human capital will then recreate positive incentive effects for individuals to work when middle aged and older. All these interactions between endogenous labour and endogenous human capital, supplied by individuals

[6]In our model in Equation (21), the government may adjust GPP, its grant to the pension system. In Belgium in the past, this was the usual policy. Also, considering the current need to cope with the effects of demographic change, the government may be forced to change (reduce) benefits without compensating parallel change in contribution rates. In our policy simulations in Section 4, this is exactly one of the cases we will study.

[7]For completeness we should add that this claim assumes that the weights p_j in Equation (19) are not higher at young age than at older age.

of different generations and ability, clearly highlight the need for a larger scale numerical analysis of pension reform.

2.7 Firms, output and factor prices

Firms act competitively on the output market. The constant returns to scale production function to produce a homogeneous good is given by

$$Y_t = K_t^{\alpha} \left(A_t H_t\right)^{1-\alpha} \quad with \quad 0 < \alpha < 1 \tag{22}$$

$$A_t = \left(1 + g_{a,t}\right) A_{t-1} \tag{23}$$

In Equation (22), K_t is the stock of physical capital at time t, while $A_t H_t$ indicates employed labour in efficiency units at that time. Technical progress is labour augmenting and occurs at an exogenous rate $g_{a,t}$. Total effective labour H_t is defined in Equation (24) as a CES-aggregate of effective labour performed by the three ability groups. In this equation λ is the elasticity of substitution between the different ability types of labour, and η_L, η_M and η_H are the input share parameters. We will impose that they sum to 1.

$$H_t = \left(\eta_H H_{H,t}^{1-(1/\lambda)} + \eta_M H_{M,t}^{1-(1/\lambda)} + \eta_L H_{L,t}^{d,1-(1/\lambda)}\right)^{\lambda/(\lambda-1)} \tag{24}$$

Effective labour supply by the high and medium ability group is specified as

$$H_{s,t} = \sum_{j=1}^{15} N_{j,s}^{t-j+1} n_{j,s}^{t-j+1} h_{j,s}^{t-j+1} \varepsilon_j, \text{ for } s{=}H{,}M \tag{25}$$

Our assumption of a competitive labour market for high and medium ability individuals implies that the total supply of effective labour will equal demand and employment for these individuals ($H_{s,t} = H_{s,t}^d$ for $s = M, H$). For low ability households, however, effective employment is lower than supply ($H_{L,t}^d < H_{L,t}$, Equation 26). There is unemployment.

$$H_{L,t}^d = (1 - u_t) \sum_{j=1}^{14} N_{j,L}^{t-j+1} n_{j,L}^{t-j+1} h_{j,L}^{t-j+1} \varepsilon_j \tag{26}$$

$$= (1 - u_t) H_{L,t} \tag{27}$$

This brings us to wage formation and union involvement. For medium and high ability labour, the labour market and wage formation are assumed to be competitive. The total wage cost per unit of effective labour will be equal to the market-clearing marginal labour productivity (Equation 28). τ_p is the employer social contribution rate. It includes the contribution cr_2 to the public pension system.

$$(1 - \alpha) A_t \left(\frac{K_t}{A_t H_t}\right)^{\alpha} \eta_s \left(\frac{H_t}{H_{s,t}}\right)^{\frac{1}{\lambda}} = w_t^s (1 + \tau_p), \text{ for } s{=}H{,}M \tag{28}$$

For low ability labour, however, wages will be above the competitive level. The existence of minimum wages or union influence are obvious possible explanations. As in Sommacal (2006) and Fanti and Gori (2011) firms will therefore choose the optimizing unemployment rate among low ability individuals (Equation 29).

$$(1 - \alpha) A_t \left(\frac{K_t}{A_t H_t}\right)^{\alpha} \eta_L \left(\frac{H_t}{(1 - u_t) H_{L,t}}\right)^{\frac{1}{\lambda}} = w_t^L (1 + \tau_p) \tag{29}$$

In the spirit of Boone and Heylen (2018), we assume a union which sets the union wage w_t^L in Equation (30) as a markup on top of a reference wage. This reference wage is a weighted average of the competitive wage $w_t^{L,c}$, the average wage of the medium and high ability group $\left(w_t^M + w_t^H\right)/2$ and the unemployment benefit. The competitive wage is the hypothetical wage that would occur if there were no unemployment among low ability households. The weights q_1, q_2 and q_3 sum to 1. We take their values from Boone and Heylen (2018). μ is the wage premium which we calibrate.

$$w_t^L = \left(q_1 w_t^{L,c} + q_2 \frac{w_t^M + w_t^H}{2} + q_3 b w_t^L\right)(1+\mu) \tag{30}$$

Furthermore, firms install physical capital up to the point where the after-tax marginal product of capital net of depreciation equals the exogenous world interest rate r_t:

$$\left[\alpha \left(\frac{A_t H_t}{K_t}\right)^{1-\alpha} - \delta\right](1-\tau_k) = r_t \tag{31}$$

with δ the depreciation rate of physical capital, and τ_k a tax paid by firms on capital returns. If the net marginal product of capital exceeds the world interest rate, capital will flow in until equality is restored. For a given interest rate, firms will install more capital when the amount of effective labour increases or the capital tax rate falls.

2.8 Fiscal government

Equation (32) describes the government's budget constraint. Its revenues consist of taxes on labour income paid by workers T_{nt}, taxes on capital T_{kt}, employer taxes on labour income T_{pt} and consumption taxes T_{ct}. They are allocated to interest payments on outstanding debt $r_t B_t$, government purchases of goods and services G_t, pension payments GPP_t, unemployment benefits UB_t and lump-sum transfers Z_t. In Equation (33), g denotes government purchases per capita adjusted for technological change. Fiscal deficits explain the issuance of new government bonds $(B_{t+1} - B_t)$.

$$B_{t+1} - B_t = r_t B_t + G_t + GPP_t + UB_t + Z_t - T_{nt} - T_{kt} - T_{ct} - T_{pt} \tag{32}$$

with:

$$G_t = g N_t A_t \tag{33}$$

$$UB_t = b \sum_{j=1}^{14} w_t^L \varepsilon_j h_{j,L}^{t+1-j} n_{j,L}^{t+1-j} u_t N_{j,L}^{t+1-j} \tag{34}$$

$$GPP_t = \text{ see Equation 21}$$

$$T_{nt} = \sum_{s=M,H} \sum_{j=1}^{15} \left(\tau_{w,j,s} - cr_1\right) w_t^s \varepsilon_j h_{j,s}^{t+1-j} n_{j,s}^{t+1-j} N_{j,s}^{t+1-j} \tag{35}$$

$$+ (1-u_t) \sum_{j=1}^{14} \left(\tau_{w,j,L} - cr_1\right) w_t^L \varepsilon_j h_{j,L}^{t+1-j} n_{j,L}^{t+1-j} N_{j,L}^{t+1-j}$$

$$T_{kt} = \tau_k K_t \left[\alpha \frac{Y_t}{K_t} - \delta\right] = \tau_k \left[\alpha Y_t - \delta K_t\right] \tag{36}$$

$$T_{ct} = \tau_c \sum_s \sum_{j=1}^{28} N_{j,s}^{t+1-j} c_{j,s}^{t+1-j} \tag{37}$$

$$T_{pt} = (\tau_p - cr_2) \sum_s w_t^s H_{s,t}^d \text{ , with } H_{s,t}^d = H_{s,t} \text{ for } s = H, M \text{ and } H_{L,t}^d = (1 - u_t) H_{L,t} \tag{38}$$

$$Z_t = z_t \sum_{j=1}^{28} N_j^{t+1-j} \tag{39}$$

Labour income taxes paid by workers $\tau_{w,j,s}$ are progressive. We model this by using a tax function

$$\tau_{w,j,s} = \Gamma \left(\frac{y_{j,s}}{\tilde{y}} \right)^{\xi} + cr_1 \text{ with } s = L, M, H, \xi \geq 0, 0 < \Gamma < 1 \tag{40}$$

where $y_{j,s}$ is gross labour income of a household of ability s and age j, and $\tilde{y}$ is average gross labour income. As we have mentioned before, the pension contribution rate cr_1 is a (non-progressive) part of the labour tax rate. As in Guo and Lansing (1998) and Koyuncu (2011), ξ and Γ govern the level and slope of the tax schedule. The marginal tax rate $\tau_{w^m,j,s}$ is the rate applied to the last euro earned:

$$\tau_{w^m,j,s} = \frac{\partial (\tau_{w,j,s} y_{j,s})}{\partial y_{j,s}} = (1 + \xi) \Gamma \left(\frac{y_{j,s}}{\tilde{y}} \right)^{\xi} + cr_1 \tag{41}$$

This means that the marginal tax rate is higher than the average tax rate when $\xi > 0$, i.e. the tax schedule is said to be progressive. Households are aware of the progressive structure of the tax system when making decisions.

2.9 Aggregate equilibrium and the current account

Optimal behaviour by firms and households and government spending underlie aggregate domestic demand for goods and services in the economy. Our assumption that the economy is open implies that aggregate domestic demand may differ from supply and income, which generates international capital flows and imbalance on the current account. Equation (42) describes aggregate equilibrium defined for all generations living at time t. The LHS of this equation represents national income. It is the sum of domestic output Y_t and net factor income from abroad $r_t F_t$ where F_t stands for net foreign assets at the beginning of t. Aggregate accumulated private wealth is denoted by Ω_t. It can be allocated to physical capital K_t, domestic government bonds B_t and foreign assets F_t (Equation 43). At the RHS of Equation (42) CA_t stands for the current account in period t. Equation (44) denotes that a surplus on the current account translates into more foreign assets. Equation (45) is the well-known identity relating investment to the evolution of the physical capital stock.

$$Y_t + r_t F_t = C_t + I_t + G_t + CA_t \tag{42}$$

with:

$$F_t = \Omega_t - K_t - B_t \tag{43}$$

$$CA_t = F_{t+1} - F_t = \Delta\Omega_{t+1} - \Delta K_{t+1} - \Delta B_{t+1} \tag{44}$$

$$I_t = \Delta K_{t+1} + \delta K_t \tag{45}$$

3 Parameterization

The economic environment described above allows us to simulate the macroeconomic, financial and welfare effects of different parametric changes in the public pension system. An important contribution in this paper is that we model and assess differential effects for individuals with different ability (education level). This simulation exercise requires us first to parameterize and solve the model. Table 1 contains an overview of all parameters. Many have been set in line with the existing literature. Others have been calibrated to match key data for Belgium in 1996-2007, the last long and fairly stable period before the financial crisis.

We have taken a first set of parameters from the literature or from existing datasets. For the discount factor β we impose a value of 0.9423, which is equivalent to a rate of time preference equal to 2% per year (see e.g. Kotlikoff et al., 2007). The value of θ, i.e. the reciprocal of the intertemporal elasticity to substitute leisure, is 2. Estimates for this parameter used in the literature, lie somewhere between 1 and 10. Micro studies often reveal very low elasticities (i.e. high θ). However, given our macro focus, these studies may not be the most relevant ones. Rogerson and Wallenius (2009) show that micro and macro elasticities may be unrelated. Rogerson (2007) also adopts a macro framework. He puts forward a reasonable range for θ from 1 to 3.

We impose a share coefficient α of physical capital of 0.375 and a depreciation rate of 4.1% per year (Feenstra et al., 2015, Penn World Table 8.1). The latter implies $\delta = 0.118$ considering that one period in the model consists of 3 years. Following Caselli and Coleman (2006), who state that the empirical labour literature consistently estimates values between 1 and 2, we set the elasticity of substitution λ between the three ability types in effective labour equal to 1.5. In the human capital production function, we choose a conservative value of 0.3 for the elasticity with respect to education time (σ). This value is within the range considered by Bouzahzah et al. (2002), but much lower than the value imposed by Lucas (1990). The literature provides much less guidance for the calibration of the relative initial human capital of low and medium ability individuals relative to the initial human capital of high ability individuals, ω_L and ω_M. To determine these parameters we follow Buyse et al. (2017) who rely on PISA science test scores. These tests are taken from 15 year old pupils, and therefore indicative of the cognitive capacity with which individuals enter our model at age 18. We use the test scores of pupils at the 17th and the 50th percentile relative to the score of pupils at the 83rd percentile, as representative for ω_L and ω_M. This approach yields values for ω_L and ω_M of 0.653 and 0.826, while ω_H=1. The parameter ξ of the tax function (cf. Equation 40) is chosen so that it generates the right amount of progressivity during the calibration period. The data with which we compare the tax function's values concern the observed differences in average personal income tax rates between three income groups in Belgium (67%, 100% and 150% of the average wage, OECD Tax Database, Table I.5). Minimizing the average root mean squared error between data and function values results in a value for ξ of 0.332. The weights used in the determination of the union's reference wage q_1, q_2 and q_3 are 0.8, 0.05 and 0.15 respectively and taken from Boone and Heylen (2018). The last parameters that we took directly from the literature are the age-specific productivity parameters ϵ_j. We follow the hump-shaped pattern imposed by Miles (1999).

A second set of 25 parameters is determined by calibration. Our procedure follows Ludwig et al. (2011). It consists of six steps which are described in greater detail in Devriendt and Heylen (2017, Section 4 and Appendix A). In brief, we start with an initial guess for these 25 parameters obtained from calibrating the model to Belgium in 1996-2007 under the assumption of being in a steady state with all exogenous variables, including demographic variables and policy variables, taken to be constant at their level of 1996-2007. The target values for the calibration are reported in the middle block of Table 1. They concern hours worked by age (averaged over the three ability types), hours worked by ability (low and medium, averaged over two large age groups), average participation in education by ability, the unemployment rate among the individuals of low ability, and wage differentials between ability groups[8]. With the obtained parameters from step 1 and data (or proxies) for the exogenous variables in 1948-50, we compute an artificial initial steady state. Next, we simulate the transition from the initial steady state to the final steady state, feeding into the model the (time-varying) fertility and survival rates, the world interest rate, the rate of technical progress and data on policy variables as exogenous driving forces. The simulated transitional paths in the calibration period may at first differ substantially from the targets. The last steps in the procedure adjust the parameters and repeat the previous steps so as to minimize the distance between the target data and the simulated data produced by the model in 1996-2007. In the end, the ratio of the model output to the data varies between 97% and 105% for all but one target variable. As to the results, we find that the calibrated taste for leisure (γ_j) declines at younger ages, and then stays flat at a low level for about 10 model periods. At higher ages, it shows a trend increase. Furthermore, we observe higher costs related to working ($T_{j,s}$) for lower ability and younger households. This confirms our presumptions that for example company cars may make transportation cheaper typically for higher ability individuals, and that costs of child care may make working more expensive for young parents.

Our calibration implies that our model's predictions very closely match the data in Belgium in 1996- 2007. Before we use the model for policy simulations, a minimal test of its validity and empirical relevance is whether it can also match the data in other periods. We did this test in Devriendt and Heylen (2017, Section 5.2). We introduced the time-varying data for the exogenous variables into the model, and then compared the model's fitted values with the data in 1960-2014 for the old-age dependency ratio, per capita GDP growth, aggregate average per capita hours worked, the capital-output ratio, participation in tertiary education, and the pre-tax Gini coefficient. We concluded that the evolution predicted by the model is in strong accordance with the evolution observed in the data. Furthermore, we compared fitted values and data for per capita hours worked in different age and different ability (or education) groups in the shorter time period 2005-2007. The match between the data and model predictions is also strong cross-sectionally.

[8]Our overall approach is to use data for individuals who did not finish higher secondary education as representative for low ability individuals, and data for individuals with a higher secondary degree but no tertiary degree as representative for medium ability individuals. Data for individuals with a tertiary degree are assumed representative for individuals with high ability. For a detailed description of the data, their construction and sources, see Devriendt and Heylen (2017, Appendix C).

Table 1: Parameterization of the model

Parameter	Description	Value
Taken from the literature or from existing datasets:		
α	Production share of capital	0.3749
λ	Elasticity of substitution between workers of different ability	1.5
θ	Inverse of the intertemporal elasticity to substitute leisure	2
δ	Depreciation rate of physical capital	0.1177
σ	Elasticity of human capital w.r.t. education time	0.3
β	Discount factor	0.9423
ε_j	Age-productivity profile by age j	$exp(0.05age - 0.0006age^2)$
q_1, q_2, q_3	Weights used in the determination of the union reference wage	0.8, 0.05, 0.15
ν_s	Shares of ability types in population	0.33
ω_M, ω_L	Relative initial human capital	$\omega_M = 0.826, \omega_L = 0.653$
Determined by calibration:		
η_H, η_M, η_L	Input shares of high, middle and low ability individuals	$\eta_H = 0.423, \eta_M = 0.334,$ $\eta_L = 0.244$
ϕ_H, ϕ_M	Efficiency parameters in human capital production function	$\phi_H = 0.466, \phi_M = 0.068$
μ	Union markup above the union reference wage	17%
$T_{j,L}$	Costs related to working - low (age 1-4; age 5-14/15)	0.004, 0.0035[(1)]
$T_{j,M}$	Costs related to working - medium (age 1-4; age 5-15/16)	0.003, 0.002
$T_{j,H}$	Costs related to working - high	0 (as reference)
γ_j	Preference for leisure	γ_1=0.7101 γ_9=0.0891 γ_2=0.2348 γ_{10}=0.0995 γ_3=0.0841 γ_{11}=0.1093 γ_4=0.0570 γ_{12}=0.1349 γ_5=0.1060 γ_{13}=0.2358 γ_6=0.0997 γ_{14}=0.2898 γ_7=0.0941 γ_{15}=0.6168 γ_8=0.0922 γ_{16}=0.6200

Target values for calibration:[(2)]

Average per capita hours worked by age, as a fraction of potential hours:

$n_1 = 0.105$	$n_5 = 0.575$	$n_9 = 0.566$	$n_{13} = 0.367$	*Education rates:*
$n_2 = 0.339$	$n_6 = 0.574$	$n_{10} = 0.544$	$n_{14} = 0.311$	$e_H = 20\%$
$n_3 = 0.502$	$n_7 = 0.574$	$n_{11} = 0.523$	$n_{15} = 0.119$	$e_M = 5\%$
$n_4 = 0.556$	$n_8 = 0.569$	$n_{12} = 0.481$	$n_{16} = 0.060$	*Unemployment rate:* $u = 12.9\%$

Average ability-specific hours worked over two large age groups:

$\frac{1}{4}\sum_{j=1}^{4} n_{j,L}$=0.405 $\frac{1}{4}\sum_{j=1}^{4} n_{j,M}$=0.373

$\frac{1}{10}\sum_{j=5}^{14} n_{j,L}$=0.439 $\frac{1}{11}\sum_{j=5}^{15} n_{j,M}$=0.486

Pre-tax earnings ratios in Belgium: low versus medium educated: 90%, low versus high educated: 69%

Fiscal and pension policy parameters in the calibration period (averaged over 1996-2007):[(3)]

$cr_1 = 0.075$	$rr_L = 0.648$	$pg = 0.979$	$\tau_k = 0.254$	$b = 0.479$
$cr_2 = 0.089$	$p_{j,H} = 0.067$	$B/Y = 0.355$	$\tau_p = 0.284$	
$rr_H = 0.577$	$p_{j,M} = 0.067$	$g = 0.002$	$\Gamma = 0.420$	
$rr_M = 0.638$	$p_{j,L} = 0.071$	$\tau_c = 0.197$	$\xi = 0.332$	

Notes: (1) The reported constants are the costs related to working per capita adjusted for technical change. (2) For more details about the data of the target values of our calibration, we refer to Appendix C of Devriendt and Heylen (2017). (3) An overview of the exogenous variables and the underlying data is provided in Appendix A.

4 Parametric public pension reform

In this section we compare the effects of various parametric public pension reforms with a baseline simulation that is driven by changing demography, technical progress and the path of the world interest rate. The past and projected future data of these exogenous variables are shown in Appendix A. In this baseline simulation all policy variables (including all parameters of the public pension system) remain constant at their 2014 values at the latest. Furthermore, in line with the specification of our model, the baseline assumes retirement at model age $j = 15$ for low ability workers and at age $j = 16$ for high and medium ability workers[9]. We focus our attention on variables related to macroeconomic performance (employment, education, per capita output), financial viability (pension expenditures), welfare and welfare inequality. We report aggregate dynamic effects as well as dynamic effects by ability group and by generation. To measure the welfare effects of policy changes for individual households, we compute the (constant) percentage change in benchmark consumption in each period of remaining life that each individual of the household should get to attain the same lifetime utility in the benchmark as after the policy shock (see also King and Rebelo, 1990)[10]. Next to welfare effects for individuals of exemplary cohorts, we also report cumulative welfare measures for all current and/or future cohorts of different abilities. Our most comprehensive aggregate welfare measure reflects the net utility gain from policy reform after the winners have hypothetically compensated all those who lose. We report the consumption volume that is equivalent to this net utility gain as a percentage of GDP in the last period before the policy reform. In all our simulations, the government ensures financial balance in the public pension system (by adjusting GPP in Equation 21), while the consumption tax rate is adjusted to maintain a constant public debt to GDP ratio.

All reforms considered are *announced* in 2014, but *implemented* in 2029[11]. From 2014 onwards, households and firms can alter their behaviour. For the welfare analysis we consider individuals of eight exemplary cohorts, being the high and the low ability households from four different generations. More precisely, the generations observed are households of age 18 to 20 in 2011-13, households of age 42 to 44 in 2011-13, households of age 66 to 68 in 2011-13 and households of age 18 to 20 in 2035-37. Note that households of age 18 to 20 in 2011-13 and especially households of age 42-44 in 2011-13 can only partially adjust their behaviour. Households of age 66-68 in 2011-13 are not directly affected by the pension reforms. Households of age 18 to 20 in 2035-37 will be living under the new policy regime during their whole life. In Appendix B we report the individual welfare effects for all current generations and the future generations that enter the model up until 2119-21. The reported cumulative welfare measures obviously include all households of current and/or future generations of specific abilities, as will

[9]Employment at higher age is thus set to zero and γ_{16} plays no role. When we simulate an increase of the retirement age, γ_{16} comes into play and n_{16} is the result of optimization by the individuals who populate our economy.

[10]To compute this percentage change we keep employment (leisure) at the benchmark.

[11]To solve the model and to perform our simulations, we choose an algorithm that preserves the non-linear nature of our model. We follow the methodology basically proposed by Boucekkine (1995) and implemented by Juillard (1996) in the program Dynare (version 4.5.4). The state of the economy in 2011-13 is identical in all simulations. Historical initial values for the endogenous and exogenous variables with lags for periods before the beginning of the simulation (i.e. 2014) were taken from the baseline simulation and were introduced in the code using the histval-command.

be specified below (see also the note below Table 2).

Figures 1 to 6 and Table 2 report our simulation results. Figures 1 to 3 and the upper part of Table 2 report the effects of the two most frequently imposed reforms to make the public pension system financially viable: macroeconomic effects (Figure 1), financial effects (Figure 2), welfare effects for 8 households (Figure 3) and aggregate welfare (Table 2). The first reform is an increase of the retirement age. From 2029 onwards, the normal retirement age is extended with one model period of three years. Households of medium and high ability will consequently face an exogenous retirement age of 66. Those of low ability will be eligible for a public pension at age 63. The second reform is a reduction in the pension benefits that households receive by lowering the public pension replacement rates. We introduce a permanent cut in these replacement rates for new retirees (from 2029 onwards) such that the present value of total savings in public pension expenditures is equal to the value obtained from extending the retirement age. This comes down to a 12.6%-points cut in rr_L, rr_M and rr_H in Equation (19).

From a macroeconomic perspective, the long-run effects of raising the retirement age are clearly better than those of a reduction in the benefit replacement rate. Compared to the baseline, the former reform implies in the long run higher per capita output, higher per capita hours worked (mainly among individuals with medium or high ability, and among older individuals) and higher investment in education. Unsurprisingly, these positive effects only manifest themselves from 2029 onwards. The main factors driving these results are the sudden increase in the active population and the decline in the number of retirees. Encouraged by the extension of the retirement age and the perspective of working longer, young higher (and medium) ability households will expand their participation in higher education. The reason is that as their career length increases with three years, the return to education rises (Cervellati and Sunde, 2013). Accumulating more human capital, they will later also earn higher wages. Moreover, given the earnings-related linkage in the pension system, this higher wage will further lead to a higher pension benefit. Last but not least, the drop in consumption taxes, resulting from lower public spending in Figure 2, reinforces the increase in purchasing power even more. The stronger accumulation of human capital and higher labour supply of older workers improve the productivity of physical capital and consequently private investment. We observe an investment boom with long-lasting effects on physical capital in 2029.

Before the actual implementation of the higher retirement age, however, effects in the opposite direction take place. From 2014 onwards, individuals anticipate that they will have to work one period of three years longer and therefore will supply slightly less labour in earlier periods (intertemporal substitution of labour) with negative effects on private investment, and GDP per capita.

The description of the effects of an extension of the retirement age directly also implies that this reform will be much less applauded by low ability individuals. They are no longer eligible to pension benefits at age 60 to 62 and should work longer (at an age when their taste of leisure is the highest), but they cannot enjoy the important gains on wages and future pension benefits from having a higher human capital. It then comes as no surprise in the left panel of Figure 3 that (especially middle aged) low ability individuals experience significant negative welfare effects caused by the reduction of leisure time. For high ability households, this negative effect is more than compensated by the increased consumption possibilities from higher wages, higher future pension benefits and lower consumption taxes. Although the latter also holds for lower ability households, this effect isn't strong enough. If we consider all current and all future generations, net aggregate welfare effects are clearly positive. We observe in Table 2 an increase equivalent to a consumption volume of 6.46% of initial GDP. Like the left panel of Figure 3, Table 2 also reveals the rising welfare inequality that we explained. Considered as a group, current generations of low ability individuals lose, while current generations of high (and medium) ability individuals win. As to future generations, the difference in welfare effects is less extreme. Both high and low ability households experience welfare gains, but high ability households again gain the most. They can optimally allocate more time to education to improve their productivity and future wage path. The latter translates (through the earnings-linkage in the public pension formula) into an increasing average pension of high ability retirees relative to low ability retirees (Figure 2.d.) and consequently leads to rising welfare inequality.

Summarizing, an extension of the retirement age improves long-run macroeconomic performance, the financial viability of the pension system and the welfare of future generations. However, current generations of low ability households experience significant welfare losses, especially those of middle and older age. The less they can optimally adjust labour supply over their life cycle, the more negative these effects are. In addition, future low ability generations experience smaller welfare gains than their high ability counterparts. Rising welfare inequality is the result[12].

The aggregate effects of a permanent reduction by 12.6%-points in the public pension replacement rates for all new retirees (from 2029 onwards) are not positive, quite on the contrary. Both from the perspective of macroeconomic performance and aggregate welfare, reducing everyone's own-earnings related pension replacement rate is a bad idea. The lower replacement rates affect the utility gain from working and studying, and cause a fall in hours worked by most individuals and a reduction of investment in human capital (Figure 1). The induced slow decrease of consumption taxes in Figure 2 (which has positive effects on the gain from work) cannot compensate this. Furthermore, undermining the marginal product of physical capital, lower effective labour will also bring about a (slight) fall in the private investment rate in physical capital. All these effects lead to a lower GDP per capita than in our baseline simulation. All current generations experience a loss of welfare in Figure 3 and Table 2. Future generations do not experience significant welfare effects compared to the baseline[13]. The only aspect in which a reduction in the replacement rates 'dominates' an increase in the retirement age relates to inequality. Now both high and low ability individuals are more or less treated equally. Relative to individuals with high ability, the pension level of individuals with low ability even increases (Figure 2.d). A major reason is that the former no longer gain from their ability to study.

[12]Li (2018) raises another important concern. Incorporating disability insurance in her model, she shows that an increase of the normal retirement age implies a significant increase of people in disability rather than in longer years of employment. Her findings can only strengthen our argument later in this section in favour of complementary policy measures raising the attractiveness of working at older age.

[13]This can be ascribed to a decreasing consumption tax rate. As more and more generations retire to whom the new lower replacement rates apply, total pension expenditures fall such that the government budget can be balanced with a lower consumption tax rate. Furthermore, leisure time increases relative to the baseline.

Figure 1: Macroeconomic effects of pension reform - part 1 (most frequent reforms)

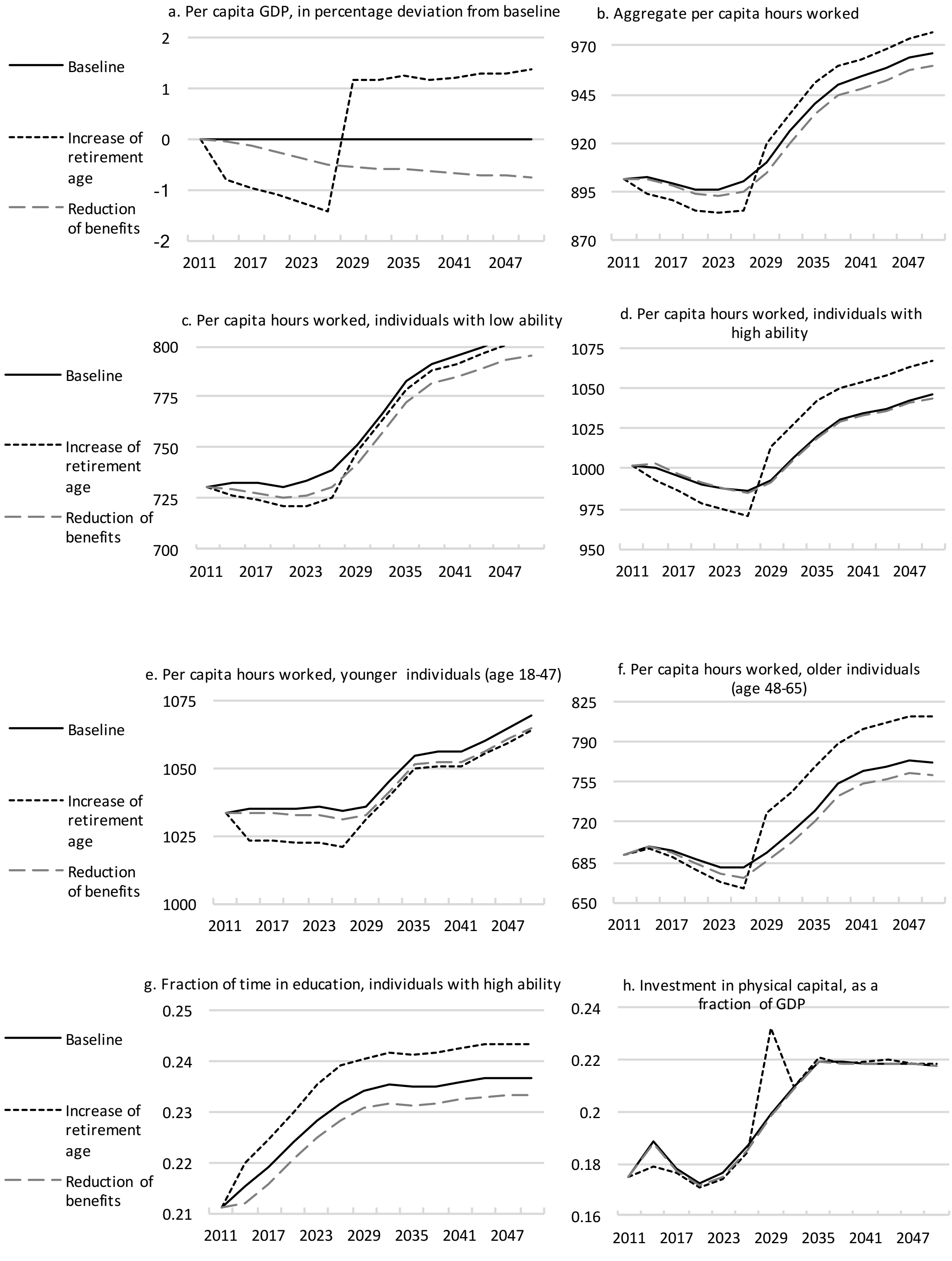


Figure 2: Financial effects of pension reform - part 1 (most frequent reforms)

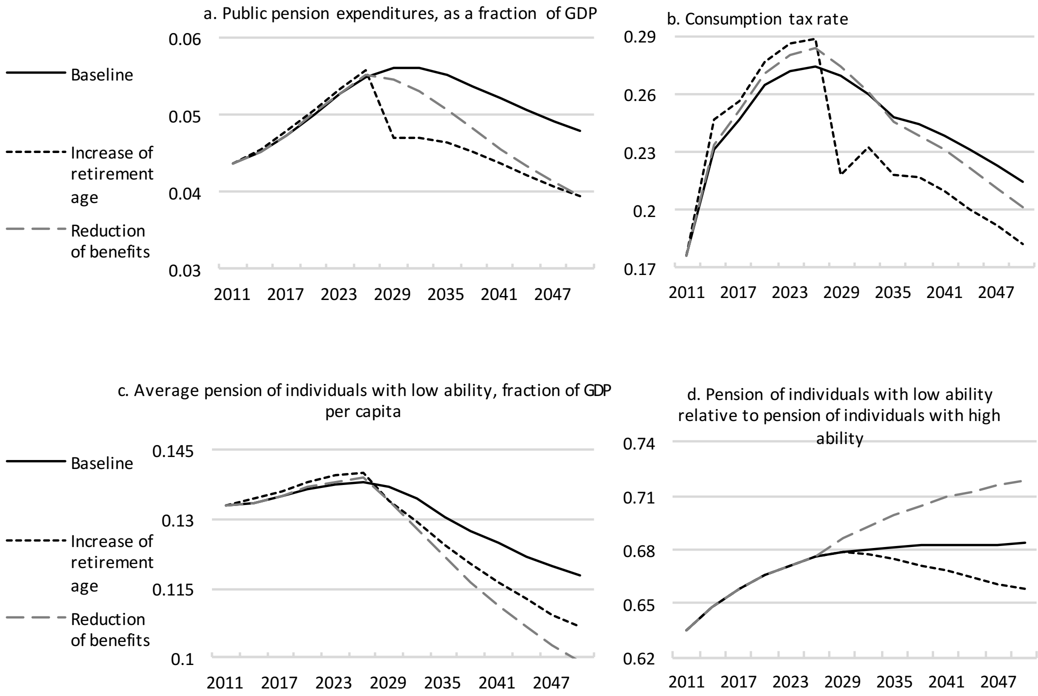
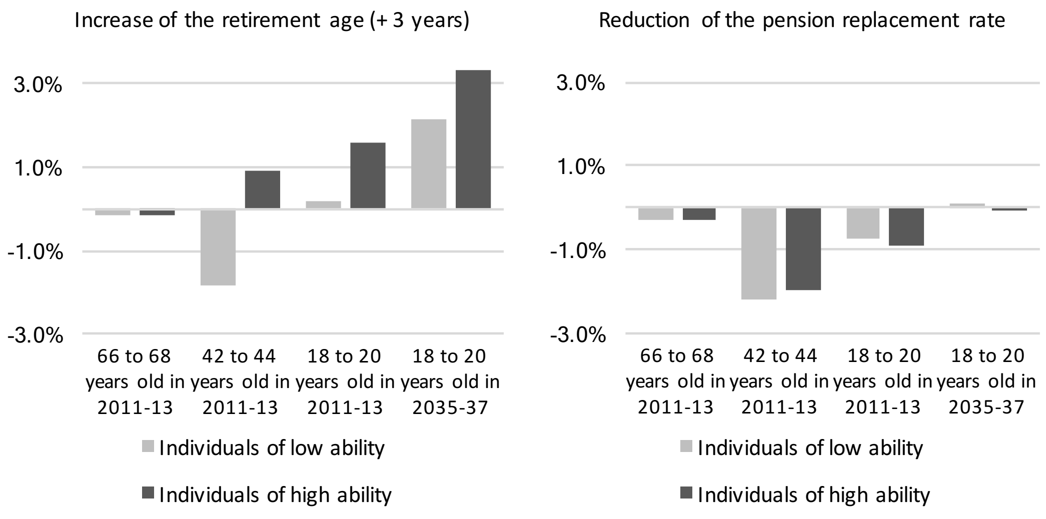


Figure 3: Welfare effects of pension reform - part 1 (most frequent reforms)



Note: Our welfare measure is the (constant) percentage change in benchmark consumption in each remaining period of life that individuals should get to attain the same lifetime utility in the benchmark as after the policy shock.

Table 2: Aggregate welfare effects of alternative pension system reforms[1]

	Total, all current and future generations[2]	All current generations	All future generations	All current generations of low ability	All future generations of low ability	All current generations of high ability	All future generations of high ability
Increase of the retirement age	6.46	1.55	4.91	-0.20	0.80	1.03	2.38
Reduction of the replacement rate	-2.7	-2.69	-0.02	-0.6	0.02	-1.27	-0.07
Rising accrual rates	4.09	2.53	1.56	0.71	0.38	1.18	0.79
Increase of retirement age and rising accrual rates	8.98	3.07	5.9	0.16	0.96	1.82	2.97
Increase of retirement age, rising accrual rates and unconditional minimum pension	2.55	-0.49	3.04	-0.04	1.21	-0.2	1.11
Increase of retirement age, rising accrual rates and changed repl. rates	8.94	3.1	5.83	0.54	1.23	1.43	2.63

(1) To compute aggregate welfare effects we take three steps. First, we compute for each cohort the present discounted value of the total change in consumption (volume) over life that is required in the benchmark to make the cohort equally well off in the benchmark as under the policy reform*. Discounting is done to 2011-13, the last period before the announcement of the policy change. For future cohorts, the present value of their total consumption change is also discounted to 2011-13. Second, we impose that all cohorts within a considered group of cohorts (e.g. all future generations of low ability) who lose under the new policy, are compensated by the winners in that group of cohorts. Third, the present discounted value of the net aggregate consumption gain of all winners after having compensated the losers is expressed in percent of GDP in 2011-13.

(2) The first three data columns include all cohorts of low, medium and high ability; the last four columns only consider cohorts of low or high ability. The results for the medium ability cohorts are fairly close to those for the high ability cohorts (available upon request).

* The basis of our computation are the data for individuals that we report in Figures 3 or 6. Cohort data follow from taking into account the size (and its expected evolution) of the cohort that individuals belong to. For young individuals the data in Figures 3 or 6 apply to many periods, whereas for the oldest individuals they only apply to one remaining period.

The negative effects that we find when benefit replacements are reduced to restore the financial viability of the public pension system, contrast with the more positive observations of e.g. Fehr (2000), Kotlikoff et al. (2007) and Kitao (2014). There are reasons for this difference. First, in our simulations contribution rates to the pension system are unchanged. They cannot fall in parallel with benefits, since it is an important objective to restore or maintain the financial balance of the system in times of ageing. For the marginal gain from work and education this is bad news. Second, in our open economy model the strong increase in savings induced by the reduction of the benefit replacement will largely flow out of the country, rather than raise domestic investment and the physical capital stock. Again, this is bad news for wages and the marginal gain from work. So it is for output.

Our simulations reveal clearly positive long-run effects on macroeconomic performance and aggregate welfare when the retirement age is increased. Welfare inequality rises, however: current generations of low ability individuals experience welfare losses, while those of high ability gain. Also future generations experience an increase in welfare, but again individuals of high ability gain more. In Figures 4 to 6 we therefore investigate alternative and broader parametric reforms which try not only to improve macroeconomic performance (productive efficiency), but also equity. Our point of reference in these figures is the simulation with increased retirement age.

The first alternative has been inspired by Buyse et al. (2013, 2017). They argue in favour of a change in the weights p_j attached to past labour income in the calculation of the pension benefit (Equation 19). Labour income earned at older age should generate more pension benefits. Labour income earned at young age (when individuals can build human capital and future productivity) should generate fewer pension benefits, reducing the opportunity cost to participation in education. The implication is an accrual rate that rises with age (for a given replacement rate, rr_s). In line with their argument, our third pension reform - indicated as 'rising accrual rates' in Figures 4 to 6 and Table 2 - reduces for all households the weights p_j attached to net labour income earned at age 18-29 to zero, and raises them for net labour income from age 48 onwards. For medium and high ability households they increase from 0.067 to 0.12 per period of 3 years. For low ability households they increase from 0.071 to 0.143. In the periods between (age 30 to 47), the weights remain unchanged at 0.067 for high and medium ability households, and 0.071 for low ability households[14]. The normal retirement age remains unchanged in this simulation. Despite this, in the long run aggregate per capita hours worked are not much lower when only accrual rates are increased (compare (1) and (2) in Figure 4.b.). In the short run, hours worked are even higher. Immediately after announcement of this reform, the average number of hours worked by older workers increases, while on average younger workers start to work fewer hours. Encouraged by the reduced opportunity cost of education when young, and the higher reward to accumulated human capital when old, individuals of medium and high ability will prefer to study. As a result, the organisation of increasing accrual rates will raise participation in higher education in Figure 4.e. much more than an extension of the retirement age. The change in hours worked and education, and their effects on the marginal productivity of physical capital, feed through in private investment in physical capital and per capita output. In the long run, per

[14]The small difference (0.067 versus 0.071) is due to the fact that the retirement age is lower for low ability households.

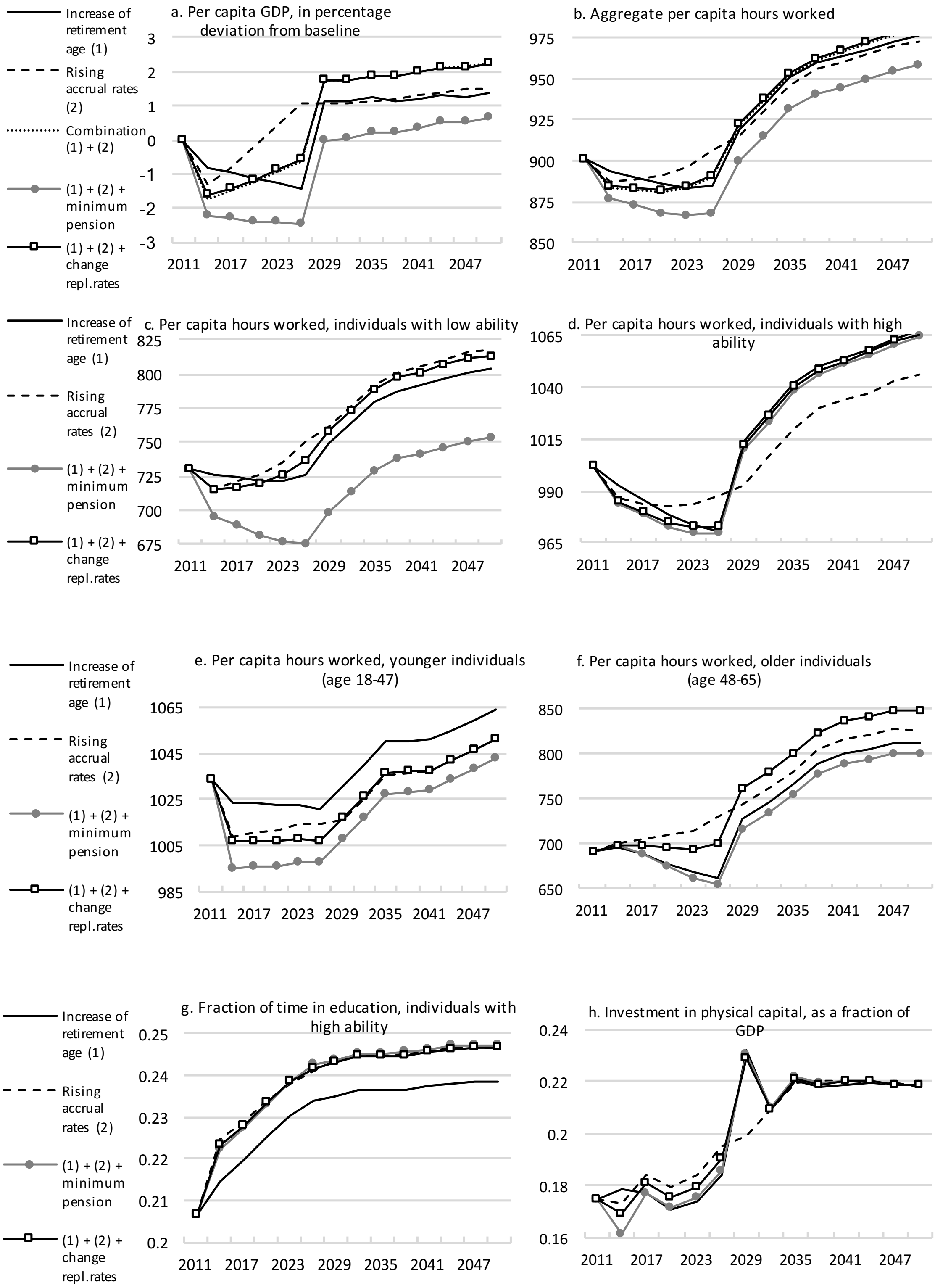
capita output is as high as when the retirement age is extended. In the short and medium-long run, however, annual per capita output is about 1% higher.

If we then consider welfare, a comparison of Figure 6.a. with the left panel of Figure 3 and a comparison of the third row in Table 2 with the first row, show much better effects for the current generations (in particular those at middle age) from the reform with rising accrual rates than from an extension of the retirement age. Moreover, the former avoids the strong increase in welfare inequality for generations that are directly affected by the reform. The downside, however, are much smaller welfare gains for future generations. We observe in Table 2 an aggregate gain for all future generations equivalent to a present discounted consumption volume of only 1.56% of GDP (compared to 4.91% of GDP after an increase of the retirement age). The main reason is that they will have to pay very high pension expenditures to currently active generations, causing future consumption tax rates to rise. Figure 5.b. reveals an increase in the consumption tax rate by 3 to 4%-points compared to the reform raising the normal retirement age. Underlying the significantly higher pension expenditures is, first, the higher number of pensioners (when the retirement age is not increased) and, second, the typical life cycle profile of labour income with individuals earning more when they are older. Attaching higher weights to labour income earned when older will consequently increase average pension benefits. As to welfare effects of current generations and welfare inequality, our results are thus fully in line with the findings of Buyse et al. (2017). For future generations, however, the results are less optimistic. The reason is that Buyse et al. (2017) did not account for demographic change and ageing (they assumed a constant population and population structure), nor for the increasing life cycle profile of labour income.

A fourth parametric pension reform combines the above-mentioned policies: the extension of the retirement age and rising pension weights by age. This unique pension policy mix exploits the complementarity of both reforms. While both improve macroeconomic performance, the former reform is financially viable, but strongly disadvantages the current generations of low ability. The latter reform has much better welfare effects for current generations of low ability and reduces welfare inequality somewhat, but is too expensive and impairs the consumption possibilities of future generations (and thus their welfare). Figures 4.a. and 4.b. show among the best macroeconomic effects from this combined policy for per capita output and labour. This also holds for education and human capital accumulation (not shown)[15]. At the same time, it reduces public pension expenditures in Figure 5.a. (although less so than when only the retirement age is increased). In Table 2 this policy also brings the best net aggregate welfare gain if we include all current and future generations. We observe a welfare increase equivalent to a consumption volume of 8.98% of initial GDP. One disadvantage remains, however. Although welfare effects for both current and future generations are better than when only the retirement age is adjusted, high ability households still win (much) more than low ability households. An additional correction to reduce welfare inequality is therefore needed.

[15] We do not show the simulation results for this combined policy in Figure 4.c.-4.h. As one can already see in Figures 4.a. and b. and 5.a. and b., its effects are hardly distinguishable from those of the last simulation shown, the simulation called "(1) + (2) + change repl. rates".

Figure 4: Macroeconomic effects of pension reform - part 2: productive efficiency and equity?



Notes: **(1)** : increase in the retirement age by 3 years (see also Figures 1 - 3). **(2)** : in all simulations in Figures 1-3 and in the first simulation in this Figure, the weights in Equation (19) have constant values of 0.067 (for s = M, H) or 0.071 (for s = L). Here, they are put at zero until age 29, and increased to 0.12 (for s = M, H) or 0.143 (for s = L) from age 48 onwards. The retirement age is not increased in this simulation. **(1) + (2) + unconditional minimum pension**: this simulation extends (1)+(2) by the introduction of a minimum pension of 42% of average net labour income in the economy. **(1) + (2) + change repl. rates**: this simulation extends (1)+(2) by increasing the replacement rate rr in Equation (19) from 64% to 72% for households of low ability and reducing it from 54% to 49% for high ability households.

Figure 5: Financial effects of pension reform - part 2: productive efficiency and equity?

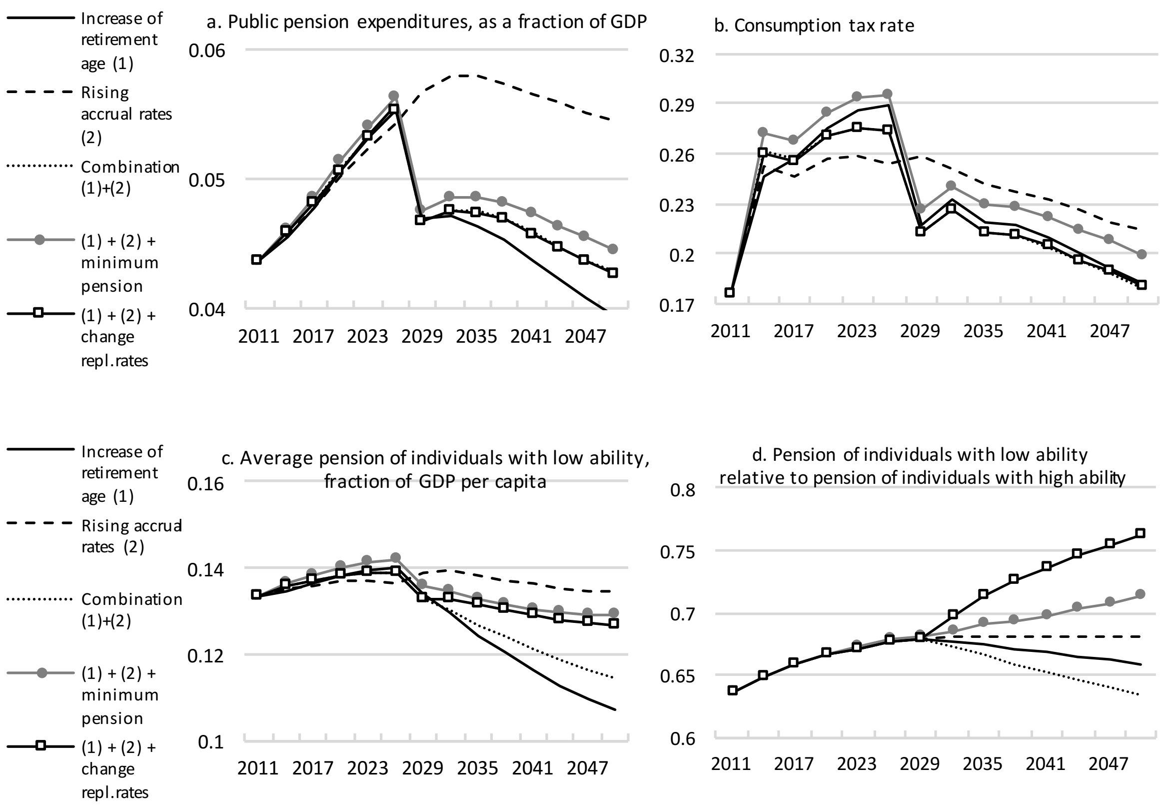
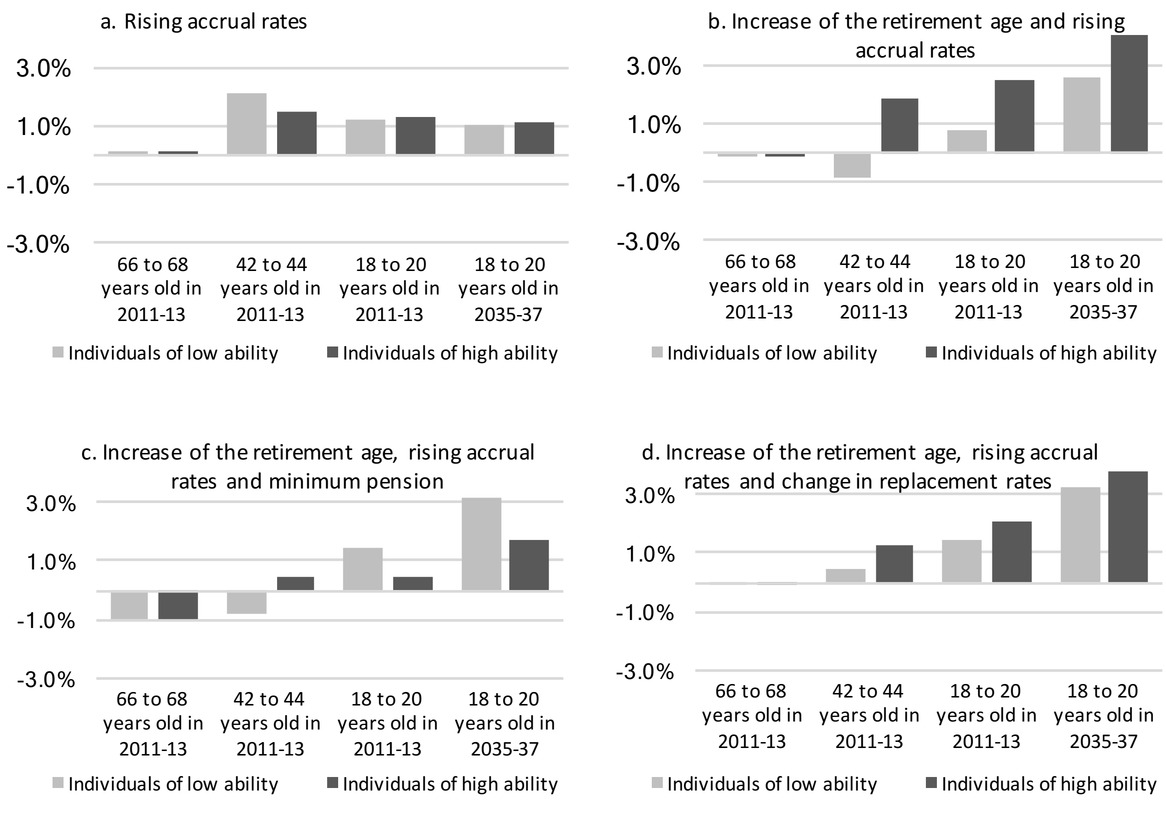


Figure 6: Welfare effects of pension reform - part 2: productive efficiency and equity?



To this end, we simulate two more parametric pension reforms. Starting from pension reform 4, pension reform 5 additionally imposes a minimum pension. Individuals are sure of a pension equal to at least 42% of the average net labour income per worker in the economy[16]. In practice the latter implies an increase in the pension level for the low ability group (see also Figure 5.c. and 5.d.), but no ex-ante change for the other two groups. The minimum pension considered here is of the unconditional type (see also Buyse et al., 2017). In a robustness check in Section 5, we also consider a minimum pension conditional on hours worked. Pension reform 6 adds to reform 4 an increase in the pension replacement rate of low ability households by 8%-points and reduces the pension replacement rate of high ability households by 5%-points. An increase in the own-earnings related replacement rate for the individuals of low ability was another key element in the pension reform preferred by Buyse et al. (2017).

Compared to reform 4, the introduction of a minimum pension and an increase of the own-earnings related replacement rate for lower ability individuals are effective in raising these individuals' welfare and in reducing inequality between low and high ability individuals. Our simulation results reveal significant progress for low ability households in Figures 6.c. and 6.d. in comparison with 6.b. Considering macroeconomic performance (productive efficiency) and the welfare of high ability individuals, however, policy reform 5 and 6 are very different. The introduction of an unconditional minimum pension strongly undermines the incentive to work for all low ability households in Figure 4.c. They now receive a public pension benefit unrelated to their own past labour supply and earnings. As a result, aggregate hours worked are seriously reduced, and so is GDP per capita. Pension reform 6 retains all the advantages of reform 4, but reduces welfare inequality by strengthening the earnings related link in the calculation of the public pension benefit for low ability households. This reform brings the best results when it comes to hours worked by low ability individuals and older individuals, without affecting hours worked by individuals of high ability. Also the effects on investment in human and physical capital are very positive. Unsurprisingly, together with aggregate hours worked, per capita GDP rises strongly in the medium to long run. In Table 2, policy 6 achieves the second best aggregate welfare increase, equivalent to a consumption volume of 8.94% of initial GDP.

5 Robustness

In reality, minimum pensions do not need to be of the unconditional type. As an alternative, we consider a minimum pension that is conditioned on the history of individuals' hours worked. More precisely, the government decides to raise the pension benefit of individuals who under the normal pension system (Equation 19) would not reach a certain threshold. Conditionality is such that the adjusted benefit depends on each individual's average life-cycle hours worked relative to the average life-cycle hours worked by all individuals retiring at that same moment. We define the conditional minimum pension at time t as

$$ppt^{t-15}_{min^c,16,L} = \frac{\frac{1}{15}\left(n^{t-15}_{1,L} + ... + n^{t-15}_{15,L}\right)}{\tilde{n}_{lc,t}} rr_{min}\tilde{y}^n_t \tag{46}$$

[16]This minimum pension is not means-tested. The individual's level of assets is not considered.

$\tilde{y}_t^n$ denotes average net labour income per worker in the economy at time t, $\tilde{n}_{lc,t}$ the average life-cycle hours worked by all individuals of all abilities who retire at time t and rr_{min} the minimum pension replacement rate determined by the government. It is set to 0.452 so that the conditional minimum pension is comparable with the unconditional minimum pension ($pp^{t-15}_{min^{uc},16,L} = 0.42\tilde{y}_t^n$) at the time of implementation. Note that we use subscript L as in practice the minimum pension only applies to the low ability group. The more an individual works over the course of his life relative to those who retire at the same moment, the higher will be his pension.[17]

The pension reform that adds to reform 4 a conditional minimum pension performs almost as well as reform 6 (see Table 3 and Figure 7), although the introduction of this type of pension proves to be somewhat more expensive and is a little less successful in reducing welfare inequality between low and high ability individuals. This comes as no surprise as in this reform the replacement rate of the high ability group remains untouched. In comparison with the unconditional minimum pension, the conditional minimum pension provides far fewer disincentives to work.

Table 3: Aggregate welfare effects of implementing a minimum pension conditioned on hours worked[(1)]

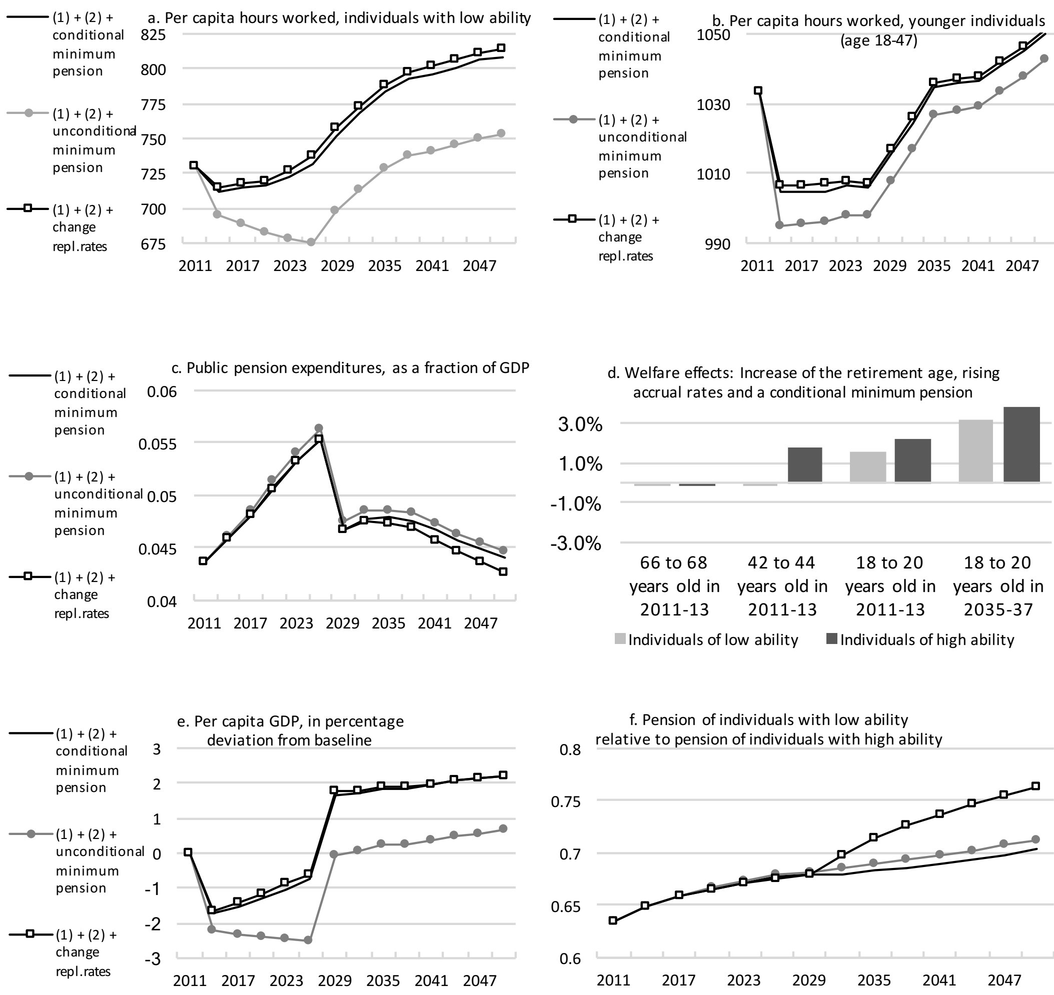
Total, all current and future generations[(2)]	All current generations	All future generations	All current generations of low ability	All future generations of low ability	All current generations of high ability	All future generations of high ability
8.79	3.17	5.62	0.5	1.23	1.68	2.64

[(1)] Details on the computation of the aggregate welfare effects are provided below 2.
[(2)] The first three data columns include all cohorts of low, medium and high ability; the last four columns only consider cohorts of low or high ability.

As a second robustness check, we evaluate whether our preferred pension reform depends on the imposed taste for leisure in model period 16 (γ_{16}). The alternative values we consider are 0.54 (lower than the γ_{16} previously used), and 0.7 (higher). Intuitively, a higher (lower) preference for leisure in the 16th period should negatively (positively) affect hours worked during that period. Working less (more) during that period, would then also lead to a lower (higher) return to education and investment in human capital. The combination of decreased (increased) labour supply and investment in education, would furthermore imply a decline (increase) in private investment and growth. This is exactly what we find when we compare the reforms with higher (lower) γ_{16} separately to their counterparts with the original value for γ_{16}, although the

[17]Implementing an unconditional minimum pension has an effect on the first-order conditions of the low ability households. They know that even when they don't work, they still will obtain the minimum pension. The derivative of the pension benefit to hours worked becomes zero. In the conditional minimum pension, however, we assume that the first-order conditions of the low ability households don't change. Our assumption comes down to imposing that individuals work as if they were under the regular pension system. If they do, and their normal pension benefit falls below the threshold, the government will raise it to the minimum pension benefit that is conditioned on relative hours worked.

Figure 7: Macroeconomic, financial and welfare effects of implementing a minimum pension conditioned on hours worked



differences are modest[18]. Comparing both sets of reforms to the baseline that is not influenced by the value of γ_{16}, we find that positive macro performance effects remain. As to the evolution of pension expenditures, the differences are negligible between the two sets of reforms because the main reason for the drop in all scenarios considered (that naturally involve an extension of the retirement age) is the sudden drop in the number of retirees.

Based on the aggregate welfare effects reported in Table C.1 in Appendix C and on the same criteria as used before, we find that the policy that combines an extension of the retirement age with rising accrual rates and a change in the replacement rates remains our preferred one, for each of the three values of γ_{16}. It comes very close to the best aggregate welfare effects over all current and future generations, and it is the most effective among the considered reforms to reduce welfare inequality.

[18]Simulation details can be made available on request.

6 Conclusion

Demographic change forces governments in all OECD countries to reform the public pension system. Increased sensitivity to rising inequality in society has made the challenge for policy makers only greater. In this paper we employ a 28 period overlapping generations model for an open economy to evaluate alternative reform scenarios. Our model explains hours worked, education and human capital accumulation, and physical capital, output, and welfare within one coherent framework. The model also incorporates heterogeneity in innate ability between individuals as the main source of inequality.

We find that frequently adopted reforms in many countries such as an increase of the normal retirement age or a reduction in the pension benefit replacement rate can guarantee the financial sustainability of the system, but they fail when the objective is also to improve macroeconomic performance without raising intergenerational or intragenerational welfare inequality. A reduction of the replacement rate to restore the financial balance of the public pension system (i.e. without a parallel reduction of contributions or labour taxes) fails on both criteria. An increase of the retirement age promotes long-run macroeconomic performance, but will create more welfare inequality. Openness of the economy and the endogeneity of human capital seem to be important elements behind these findings.

Our results prefer a reform that combines an increase of the retirement age, which decreases pension expenditures relative to GDP, with an intelligent design of the linkage between the pension benefit and earlier labour earnings. First, this design conditions pension benefits on past individual labour income, with a high weight on labour income earned when older and a low weight on labour income earned when young. Such a linkage between the pension benefit and earlier labour income provides strong incentives to invest more in education by reducing its opportunity cost when young, and stimulates working more hours when older. Second, to avoid rising welfare inequality this linkage is complemented by a strong rise in the benefit replacement rate for low ability individuals (and a reduction for high ability individuals). Low ability individuals in our model are not productive in education at the tertiary level. Since their low ability is a circumstance for which they cannot be held responsible, a compensation mechanism is justified. Attempts to cope with rising inequality by introducing an unconditional minimum pension are negative for aggregate employment and welfare. Alternatively conditioning the level of the minimum pension on an individual's hours worked over the career brings much better results, which are fairly close to those of our preferred reform.

Appendices

A Exogenous variables

This Appendix gives more details about the exogenous variables that we used in the calibration of the model in Section 3, and to obtain our baseline simulation in Section 4.

A.1 Demography

f_t: fertility rates
Data source: population by age since 1948 (Bevolkingsvooruitzichten 2015-2060 of the Belgian Federal Planning Bureau and Statistics Belgium)
Computation: We divided the population of age 18 to 20 during three years by the population of age 18 to 20 in the previous three years. The fertility rates are displayed in Figure **??**. As to the impact of migration, both natives and immigrants of age 18 to 20 are included in the youngest generation. They affect population dynamics in our model. People who enter or leave the country after the age of 20 do not. Children of immigrants are included in the fertility rate when they become 18.

sr_j^t: conditional survival rates
Data sources: Statistics Belgium, Mortality rates before 1998 are by age category (sometimes 4 years, sometimes 5) and start from 1946. As of 1998 data are annual. Prospects were provided by the Belgian Federal Planning Bureau and Statistics Belgium (Bevolkingsvoorzichten 2015-2060).
Computation: Survival rates were calculated by substracting the mortality rate from 1. Some conditional survival rates are shown in Figure A.1.

Figure A.1: Age-specific conditional survival rates in Belgium

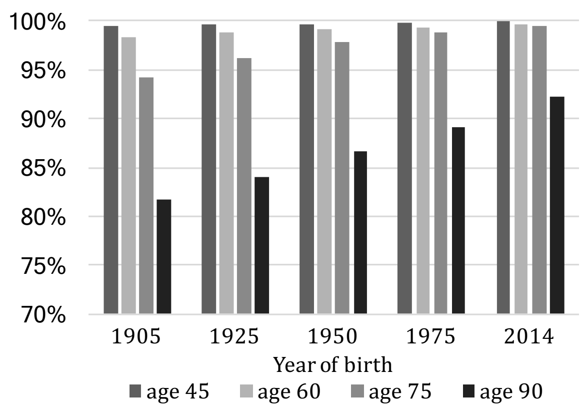
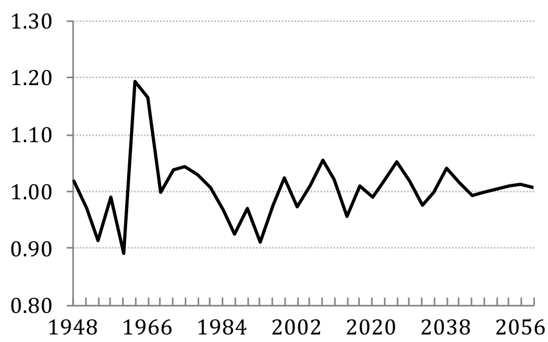


Figure A.2: Fertility rate since 1948



A.2 World real interest rate

The assumption of an open economy with perfect capital mobility implies that the net after-tax rate of return on physical capital will always be equal to the (exogenous) world real interest rate r_t. It requires us to introduce data for this interest rate over a very long period of time. To the best of our knowledge, however, this is not readily available. Krueger and Ludwig (2007) and - more recently - Marchiori et al. (2017) have computed highly relevant series using an OLG model and taking into account projections for future demography at the world or OECD level. Their results are fairly similar, but their data do not cover the whole period since 1950. To get data also for the earliest decades, we relied on the US stock market data from Shiller (2015). Figure A.3 includes his cyclically-adjusted earnings/price ratio in %. We take it as a proxy for the return to physical capital in the world in the 20th century. Combining this proxy with the simulated real interest rate series for 2000-2050 from Marchiori et al. (2017), and smoothing using a third degree polynomial, yields our world real interest rate.

A.3 Rate of technical progress

Figure A.4 displays the exogenous rate of labour augmenting technical change ga_t since 1951. Our main source is Feenstra et al. (2015, Penn World Table 8.1). We used their data for TFP growth until 2011, after a double adjustment. First, a correction was necessary for the different treatment of hours worked[19]. Second, we HP-filtered the corrected data to obtain the trend rate of technical change and to exclude cyclical effects. For the years until 2021, we approximate ga_t by productivity per hour worked as projected by the Federal Planning Bureau (2016). Missing data in between both periods are determined by lineair interpolation. As of 2022, we use productivity per worker as advanced by the Belgian Studiecommissie voor de Vergrijzing (2016) as a proxy. The projected 1.5% annual growth rate after 2034 also corresponds to the projection for the rate of technical progress of the 2015 European Commission's Working Group on Ageing.

Figure A.3: Annual world interest rate

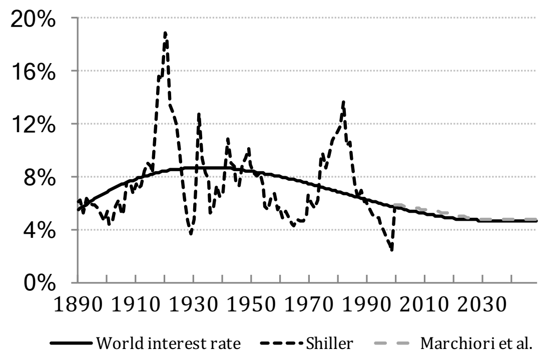
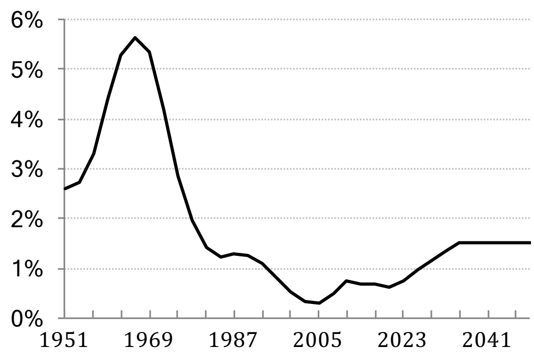


Figure A.4: Average annual rate of technical progress



[19]The Penn World Table 8.1 includes data for TFP (rtfpna) which correspond to the following production function: $Y = BK^{\alpha}(hc.L)^{1-\alpha}$, with B the level of TFP, K physical capital, hc human capital and L employment (in persons). Using comparable notation, our production function would be $Y = K^{\alpha}(A.hc.L.h)^{1-\alpha}$ with h hours worked per employed person. It then follows that $B = (A.h)^{1-\alpha}$. The relevant growth rate of A in our model can then be approximated as the growth rate of B (or rtfpna in PWT) divided by the labour share $(1-\alpha)$ minus the growth rate of hours worked per employed person.

A.4 Fiscal policy and pensions

Γ_t: overall average household tax rate on gross labour income (% of gross wage)
Data sources: OECD Government Revenue Statistics, Details of tax revenue - Belgium, and OECD Economic Outlook (available via OECD.Stat).
Computation: Total tax revenues of individuals on income and profits (code 1110) plus social security contributions (code 2100) are divided by the gross wage bill.

τ_p: employer social contribution rate (% of gross wage)
Data sources: OECD Government Revenue Statistics, Details of tax revenue - Belgium, and OECD Economic Outlook (available via OECD.Stat).
Computation: we divide the social contributions paid by employers (code 2200) by private gross wage bill (the gross wage bill minus government wages).

τ_c: Consumption tax rate (in %)
Data source: McDaniel (2007, updated 2014).

τ_k: Tax rate on capital returns
Data sources: after 1982: effective marginal corporate tax rates taken from Devereux et al. (2002). The data for 1970-1981 were extrapolated based on the evolution of Belgium's statutory corporate income tax rates.

g: government spending on goods and services as a fraction of GDP
Data sources: The data include government consumption and fixed capital formation (OECD Economic Outlook No 98)

rr_L, rr_M, rr_H: net own-earnings related pension replacement rates
Data sources and description: OECD Pensions at a Glance (2005,2007,2009,2013) presents net pension replacement rates for individuals at various multiples of average individual earnings in the economy. Taking into account that relative to average earnings, earnings of the low (no upper secondary degree), medium (upper secondary degree) and high ability group (tertiary degree) are 86%, 95% and 122% (OECD Education at a Glance, 2011), we consider the data for individuals at 87,5% of average earnings as representative for the low ability group, individuals with average earnings as representative for the medium ability group, and individuals with 125% of average earnings as representative for the high ability group. Country studies show the composition (sources) of this net replacement rate. Our proxy for rr_s includes all earnings-related pensions and mandatory occupational pensions when they depend on wages or hours worked. Data before 2002 are extrapolated using Scruggs (2007), Ebbinghaus and Gronwald (2009), and Cantillon et al. (1987).

Other pension policy parameters:
Other policy variables are the pension weights p_j with $j = 1 - 15$ for the medium and high ability group and $j = 1 - 14$ for the low ability group. In correspondence with the Belgian pub-

lic pension system which imposes equal weights, we set them all to 1/15 and 1/14 respectively. For the computation of the public pension of low skilled workers, periods of unemployment are considered equivalent to periods of work, also in correspondence with the system in Belgium. Both the revaluation factor applied to past labour income in the determination of the pension benefit of new retirees wg, and the revaluation factor applied to adapt pension benefits of existing retirees to increased living standards pg follow the Belgian reality. In Belgium, only labour income earned between 1955 and 1974 underwent real revaluations according to wg^n with $n = 1$ in 1974, $n = 2$ in 1973, ..., $n = 20$ in 1955 and $wg = 1.036$ in 1974-1996, $wg = 1.032$ in 1997, $wg = 1.028$ in 1998, ..., $wg = 1$ as of 2005 (Festjens, 1997). pg is set to 1 before 1969, 1.023 annually between 1969 and 1992, 0.993 between 1993 and 2013, 1.003 for 2014-15, 1.005 for 2016-21 and 1.002 afterwards. Data before 1984 are from Festjens (1997). Observations until 2015 and future values were taken from Studiecommissie voor de Vergrijzing (2016). The contribution rates of individuals and firms to the first pillar pension scheme cr_1 and cr_2 are 7.5% and 8.9% respectively (OECD Pensions at a Glance, 2013).

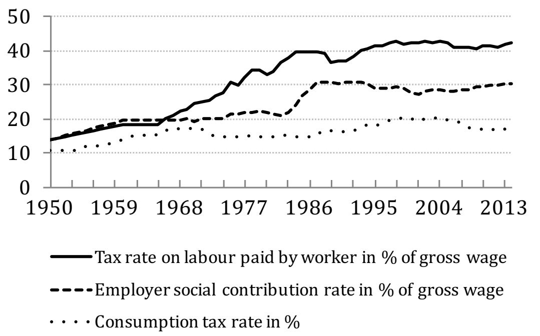
b: Gross unemployment benefit replacement rate for the low ability group
Data sources and description: OECD Database on Benefit Entitlements and Gross Replacement Rates for data going from 1961 to 2007. The reference earnings are 67% of average earnings. For 2008-2014, we extrapolate this data series with the trend observed in the gross replacement rates for an individual that has average earnings (OECD Benefits and Wages, Gross Replacement Rates). In model period 14, $(1-\tau_{w,L}-b)/2$ is added as a bonus to the benefit replacement rate as to account for the Belgian redundancy pay system (stelsel van werkloosheid met bedrijfstoeslag or SWT).

B: General government consolidated gross debt in % of GDP
Data source: EU Commission, AMECO, series UDGGL.

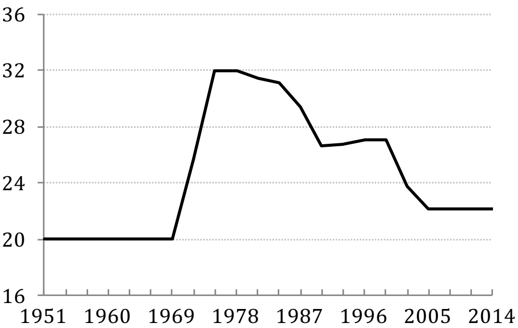
In the baseline simulation all policy parameters are kept constant at their 2014 level.

Figure A.5: Fiscal and pension policy variables

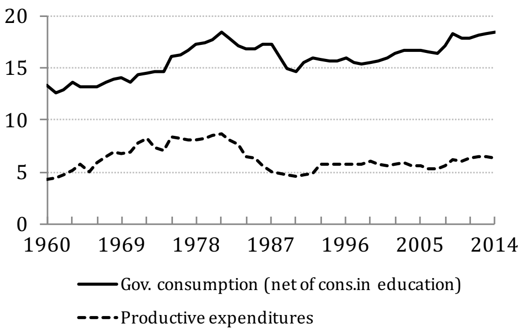
(a) Labour and consumption tax rates in %



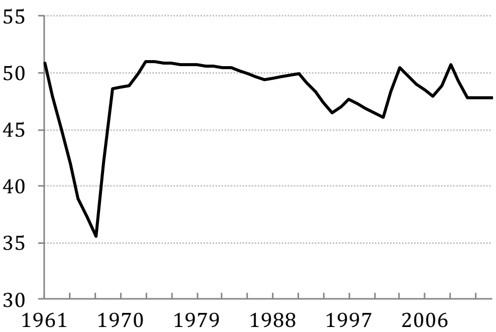
(b) Effective marginal corporate tax rate in %



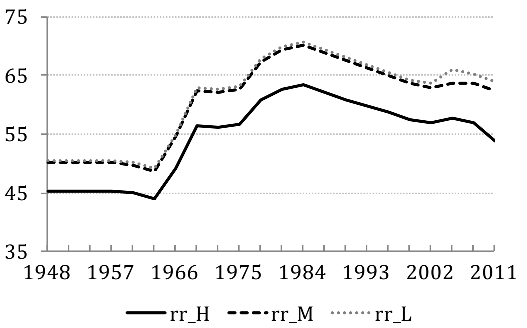
(c) Government consumption and productive expenditures in % of GDP[(1)]



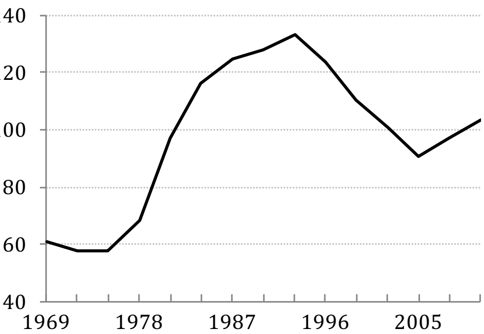
(d) Gross unemployment benefit replacement rate in %[(1)]



(e) Public pension replacement rates in %



(f) General government consolidated gross debt in % of GDP[(1)]



Note: (1) Earlier data are assumed to be equal to their level in the earliest available year.

B Welfare effects of pension reform: individuals of all current and future generations by ability

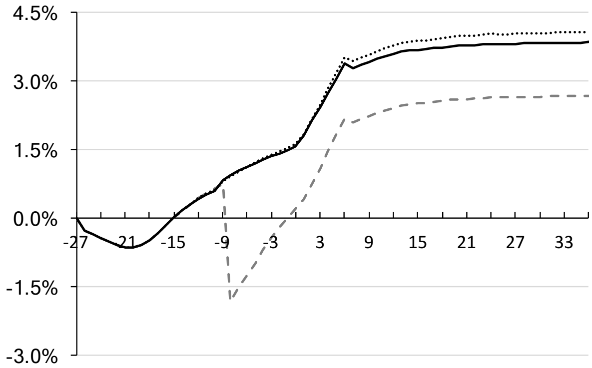
The welfare effects depicted in Figure B.6, show for all individuals considered the percentage change in benchmark consumption necessary in all remaining periods of life to obtain the same lifetime utility in the benchmark as after the reform. We consider all generations alive in 2011-13, i.e. those that are 18-101 in 2011-13, and all future generations up until those that enter the model in 2119-21. We report on the vertical axis the welfare effect of the generation that entered the model in $t + k$, where k is indicated on the horizontal axis, and where t is the period right before the pension reform is announced or 2011-13. The reform itself is implemented in $t + 6$. All generations with $k < -9$ will have retired by the implementation moment. For example, extending the retirement age implies in panel (a) a welfare loss for low ability individuals that were 27 to 29 year old in 2011-13 ($k = -3$, they were 18 to 20 in 2002-04) of 0.44% benchmark consumption. Individuals of low ability that are 18 to 20 in 2020-22 ($k = 3$) experience a welfare gain of 1.1% of benchmark consumption.

C Robustness: aggregate welfare effects of pension reform for alternative values of γ_{16}

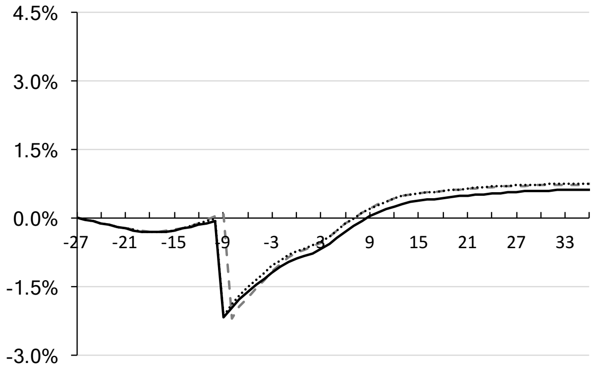
Table C.1 provides the aggregate welfare effects of different pension reforms conditional on the value for γ_{16}. In the five bottom rows, values without brackets correspond to welfare effects based on a high value of γ_{16} (0.70), values with brackets denote welfare effects based on a low value of γ_{16} (0.54). The original value of γ_{16} is 0.62. The 'rising accrual rates' and 'reduction of the replacement rate' pension reforms displayed in the first two rows, are not influenced by the value of γ_{16}, but are reported as a reference.

Figure B.6: Welfare effects of pension reform: individuals of all current and future generations by ability

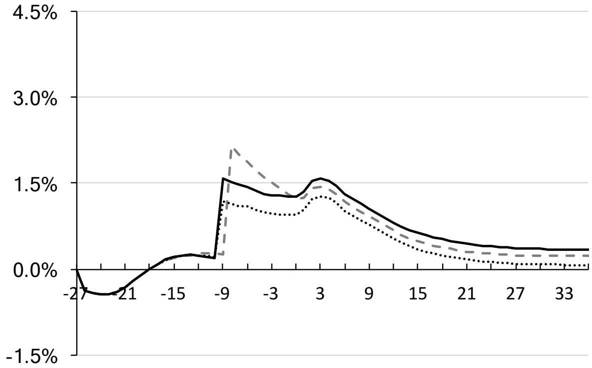
(a) Increase of retirement age



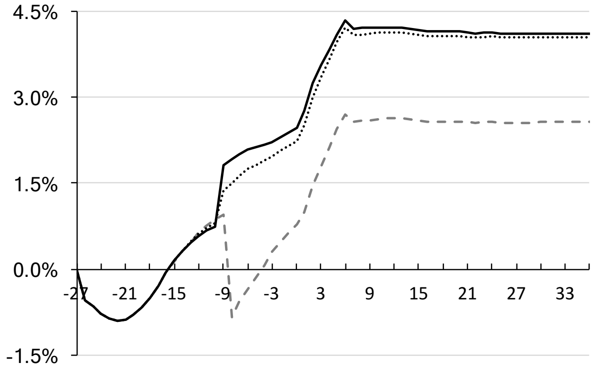
(b) Reduction of benefits



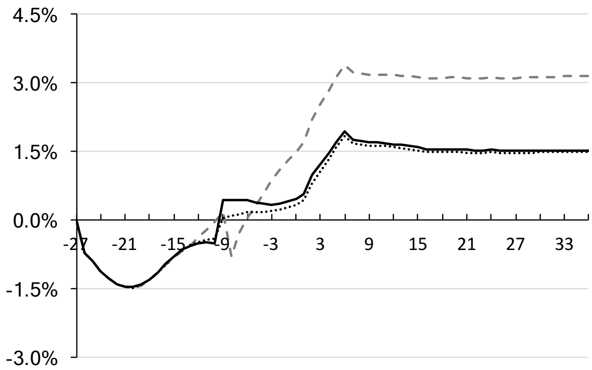
(c) Rising accrual rates



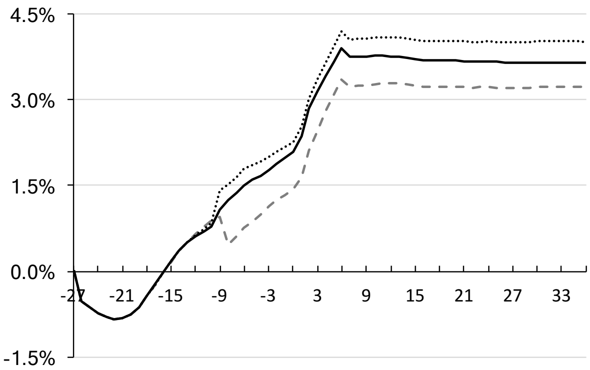
(d) Increase of retirement age and rising accrual rates



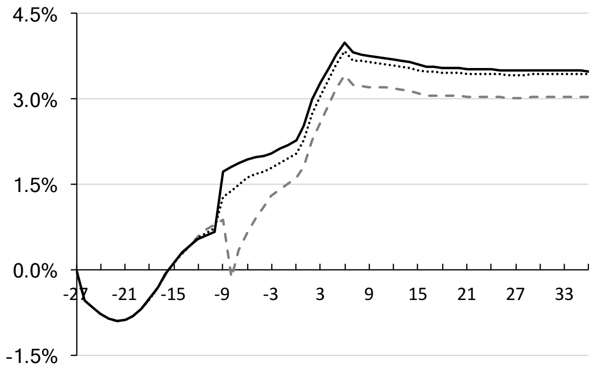
(e) Increase of retirement age, rising accrual rates and an unconditional minimum pension



(f) Increase of retirement age, rising accrual rates and change in rep. rates



(g) Increase of retirement age, rising accrual rates and a conditional minimum pension



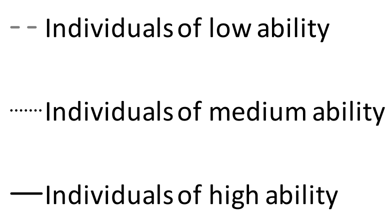


Table C.1: Aggregate welfare effects of pension reform for alternative values of γ_{16}[1]

	Total, all current and future generations[2]	All current generations	All future generations	All current generations of low ability	All future generations of low ability	All current generations of high ability	All future generations of high ability
Rising accrual rates	4.09	2.53	1.56	0.71	0.38	1.18	0.79
Reduction of the replacement rate	-2.7	-2.69	-0.02	-0.6	0.02	-1.27	-0.07
Increase of the retirement age	5.12 (7.93)	0.97 (2.19)	4.14 (5.74)	-0.3 (-0.1)	0.63 (0.98)	0.72 (1.37)	2.01 (2.79)
Increase of retirement age and rising accrual rates	7.67 (10.43)	2.5 (3.72)	5.17 (6.71)	0.07 (0.25)	0.8 (1.12)	1.51 (2.17)	2.60 (3.37)
Increase of retirement age, rising accrual rates and unconditional minimum pension	1.22 (4.01)	-1.08 (0.16)	2.3 (3.84)	-0.15 (0.07)	1.05 (1.39)	-0.51 (0.14)	0.75 (1.50)
Increase of retirement age, rising accrual rates and changed repl. rates	7.62 (10.39)	2.52 (3.75)	5.09 (6.64)	0.45 (0.63)	1.07 (1.4)	1.12 (1.78)	2.27 (3.03)
Increase of retirement age, rising accrual rates and conditional minimum pension	7.47 (10.23)	2.59 (3.81)	4.89 (6.42)	0.40 (0.59)	1.07 (1.39)	1.37 (2.02)	2.28 (3.04)

[1] Details on the computation of the aggregate welfare effects are provided below Table 2.

[2] The first three data columns include all cohorts of low, medium and high ability; the last four columns only consider cohorts of low or high ability.

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