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Willem Devriendt and Freddy Heylen*

Department of Economics, Ghent University, Sint-Pietersplein 6, 9000 Ghent, Belgium
*Corresponding author. E-mail: freddy.heylen@ugent.be

Introduction

This supplementary appendix contains details on (A) the individuals' first-order conditions, (B, C) the construction and sources of our data on employment, education, earnings, demography, and all fiscal policy and pension policy parameters, (D) the imposed world interest rate counterfactuals and a related robustness test, and (E) additional simulation results for individual cohorts.

A First-order conditions of households

The law of motion of optimal consumption over time is denoted by the Euler equation (1). Adding the posibility of death ($sr_j^t < 1$) to the model implies that the consumption path becomes flatter. Since conditional survival rates drop as an individual ages, it will from a certain age turn negative. This happens when the conditional survival rate falls below $1/(\beta(1+r_t))$. Increased life expectancy, modelled as rising survival rates, will postpone this turning point.

$$\frac{c_{J+1,s}^t(1+\tau_c)}{c_{J,s}^t(1+\tau_c)} = \beta sr_J^t(1+r_{t+J}) \tag{1}$$

The optimal labour-leisure choice for medium and high ability households is described by Equation (2). Low ability households face exactly the same choice, although they retire sooner. In each period, individuals will supply labour up to the point where the (discounted) marginal utility of leisure equals that of labour. The latter is elaborated on the right-hand side. Working one more hour in the considered period yields more resources to consume and more utility in that period itself (first term RHS), but also when retired (second and third term RHS). The gain from work in the period itself will rise when the wage, the productivity level, the probability to survive and the human capital stock are higher and when the initial consumption level, the tax levels on labour and consumption, and the transport and child care costs are lower. The

second term captures the extra consumption possibilities resulting from working more during period J in the first period of retirement (model-age 16), the third term the extra consumption possibilities in all other years of retirement. These consumption possibilities depend, next to those determinants already mentioned, positively on the earnings-linked replacement rate, rr_s, the real interest rate r, the revaluation measure applied to past labour income wg, and the pension revaluation factor pg.

$$\beta^{J-1}\pi_J^t \frac{\gamma_J}{\left(l_{J,s}^t\right)^\theta} \frac{-\partial l_{J,s}^t}{\partial n_{J,s}^t} = \frac{\beta^{J-1}\pi_J^t \left(w_{t+J-1}^s \varepsilon_J h_{J,s}^t \left(1-\tau_{w^m,J,s}^t\right) - T_{J,s}^t\right)}{c_{J,s}^t \left(1+\tau_c\right)}$$
$$+ \sum_{j=16}^{28} \frac{\beta^{j-1}\pi_j^t}{c_{j,s}^t \left(1+\tau_c\right)} \frac{\partial ppt_{j,s}^t}{\partial n_{J,s}^t}, \text{ for } J = 1-15,\ s = M, H \tag{2}$$

with

$$\frac{\partial ppt_{16,s}^t}{\partial n_{J,s}^t} = rr_s \frac{1}{15} w_{t+J-1}^s \varepsilon_J h_{J,s}^t \left(1-\tau_{w^m,J,s}^t\right) \prod_{l=J}^{15} wg_{t+l}$$

and

$$\frac{\partial ppt_{j,s}^t}{\partial n_{J,s}^t} = \frac{\partial ppt_{16,s}^t}{\partial n_{J,s}^t} \prod_{l=16}^{j} pg_{t+l-1}, \text{ for } j > 16$$

Equation (3) states that the marginal utility loss from investing in education in period J for $s = M, H$ must equal the (discounted) marginal utility gain over life. The LHS makes clear that spending time in education is not rewarded in the same period: one loses leisure time. In return, however, this investment will yield extra consumption possibilities in later periods. Due to the rise in human capital, working will be rewarded more due to increased productivity and consequently labour income. This increase in labour income will -ceteris paribus- also translate into a higher pension benefit.

$$\beta^{J-1}\pi_J^t \frac{\gamma_J}{\left(l_{J,s}^t\right)^\theta} \frac{-\partial l_{J,s}^t}{\partial e_J^t} = \sum_{j>J}^{15} \beta^{j-1}\pi_j^t \left(\frac{w_{t+j-1}^s \varepsilon_j n_{j,s}^t \left(1-\tau_{w^m,j,s}^t\right)}{c_{j,s}^t \left(1+\tau_c\right)} \frac{\partial h_{j,s}^t}{\partial e_J^t} \right)$$
$$+ \sum_{j=16}^{28} \beta^{j-1}\pi_j^t \left(\frac{1}{c_{j,s}^t \left(1+\tau_c\right)} \frac{\partial ppt_{j,s}^t}{\partial e_J^t} \right), \text{ for } J = 1-4,\ s = M, H \tag{3}$$

with

$$\frac{\partial h_{j,s}^t}{\partial e_J^t} = \frac{\partial \left[h_{1,s}^t \left(\prod_{i=2}^{j} x_{i,s}^t\right)\right]}{\partial e_J^t} = h_{1,s}^t \left(\frac{\partial x_{J+1,s}^t}{\partial e_J^t} \prod_{\substack{i=2 \\ i \neq J+1}}^{j} x_{i,s}^t \right), \text{ for } j = 2-5$$

with $x_{i+1,s}^t = \left(1 + \phi_s \left(e_{i,s}^t\right)^\sigma\right)$, and

$$\frac{\partial h_{j,s}^t}{\partial e_J^t} = \frac{\partial h_{5,s}^t}{\partial e_J^t}, \text{ for } j > 5$$

and

$$\frac{\partial ppt_{16,s}^t}{\partial e_J^t} = rr_s \frac{1}{15} \sum_{j>J}^{15} \left(w_{t+j-1}^s \varepsilon_j n_{j,s}^t \left(1-\tau_{w^m,j,s}^t\right) \frac{\partial h_{j,s}^t}{\partial e_J^t} \prod_{l=j}^{15} wg_{t+l} \right)$$

and

$$\frac{\partial ppt^t_{j,s}}{\partial e^t_J} = \frac{\partial ppt^t_{16,s}}{\partial e^t_J} \prod_{l=16}^{j} pg_{t+l-1}, \text{for } j > 16$$

B Employment, education rates and earnings ratios in Belgium

B.1 Annual hours worked per capita

For each ability group annual hours worked per capita are computed as the employment rate in persons multiplied by annual hours worked per employed person. In the description of the model, the supply of labour hours is expressed as a fraction of potential hours. This fraction is denoted by $n^t_{j,s}$. Our proxy for potential hours per person is 40 hours per week during 52 weeks per year. For individuals of high and medium ability $n^t_{j,s}$ will also be the fraction of hours actually worked. For individuals of low ability, who can be unemployed, the fraction of hours worked is $n^t_{j,L}(1-u_t)$. Reported hours will be higher if a larger fraction of those in an age or skill group are employed, and if those employed work more hours. We report the data by age and ability averaged over 1996-2007 in Figure B.1.

Data sources and computation:

Employment rate in persons by age and ability (education): As proxy for the high ability group, we use data for individuals with a tertiary degree. The representative individual of medium ability will have a higher secondary degree, but no tertiary degree. The representative lower ability individual will obtain a lower secondary degree at best. We show the data in Figure B.2. Data source: EUROSTAT, Employment rates by sex, age and highest level of education attained, lfsa_ergaed.

Annual hours worked per employed person: The data are computed as weekly hours worked multiplied by the average number of weeks worked per year. The former differ by age and by ability (see Figure B.4, and our description below). Due to lack of data, the latter are assumed to be the same for all workers.

Hours worked per week by age: OECD Stat (Labour Force Statistics, Average usual weekly hours worked on the main job).

Hours worked per week by ability: We combine data from ILO, which links professions to education levels, with data from Eurostat on weekly hours worked by profession. ILO links professions categorized in ISCO-08 groups to ISCED-97 levels of education. As the low ability group corresponds to ISCED-97 groups 1 to 2 (primary and lower secondary education), the medium group to groups 3 and 4 (upper secondary or post-secondary, non-tertiary education), and the high ability group to ISCED-97 groups 5 and 6 (tertiary education), the professions of low, medium and high ability are composed as follows. Low ability individuals can be found among clerical support workers, service and sales workers, craft and related trades workers, plant and machine operators and assemblers, and workers in elementary occupations. Medium ability

workers can be found in the same occupations, but not in elementary occupations. We expect high ability individuals to be ISCO-08 technicians and associate professionals, professionals, and managers. Data sources: ILO (2012), International standard classification of occupations, structure, group definitions and correspondence tables. EUROSTAT, Average number of usual weekly hours of work in the main job, by sex, professional status, full-time/part-time and occupation, lfsq_ewhuis). The data concern dependent employees.

Average number of weeks worked per year: average annual hours actually worked per worker (dependent employment) divided by average usual weekly hours worked on the main job by all workers (dependent employment). OECD Stat, Labour Force Statistics, Hours worked.

Unemployment rate among individuals of low ability: As a proxy we use data on the unemployment rate among individuals without higher secondary education. EUROSTAT, Unemployment rates by sex, age and educational attainment, lfsa_urgaed. Figure B.3.

Figure B.1: Annual per capita hours worked by ability (education) and age (averaged over 1996-2007)

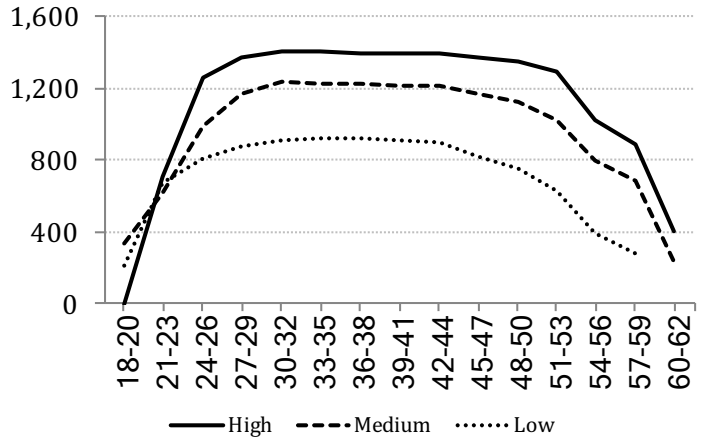


Figure B.2: Employment rate in persons by ability and age (in %, avg 1996-2007)

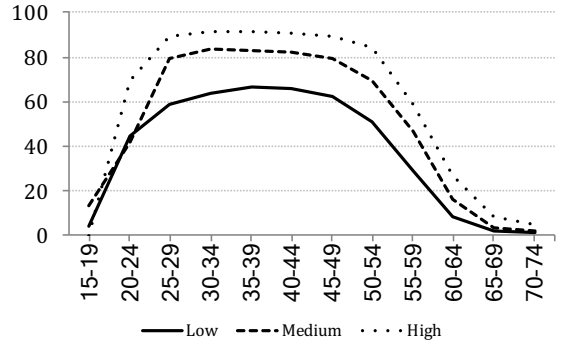


Figure B.3: Unemployment rate among individuals of age 15 to 64 without higher secondary degree (in %)

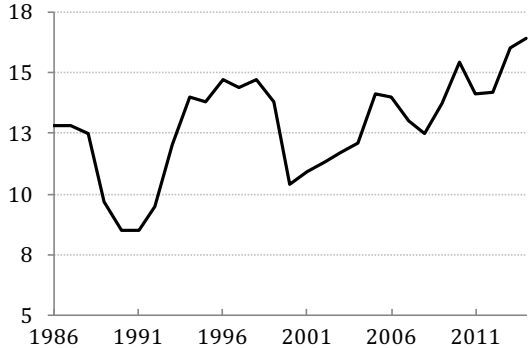
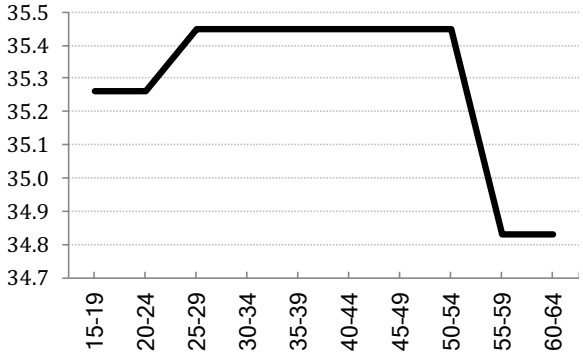
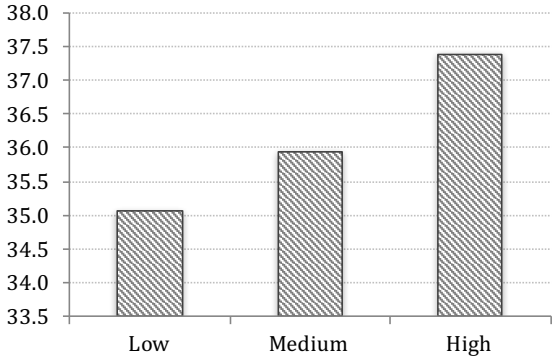


Figure B.4: Hours worked per week

(a) per person by age (dependent employment, avg 1996-2007)



(b) by ability-type



B.2 Education rate: the participation rate in education in hours

The participation rate in education in hours (e) follows from multiplying the participation rate in persons by actual to potential annual hours studied per student, and the so-called completion rate. Equation (4) and our explanation below illustrate the computation of the data that set the calibration target for the education rate among high ability individuals in the model.

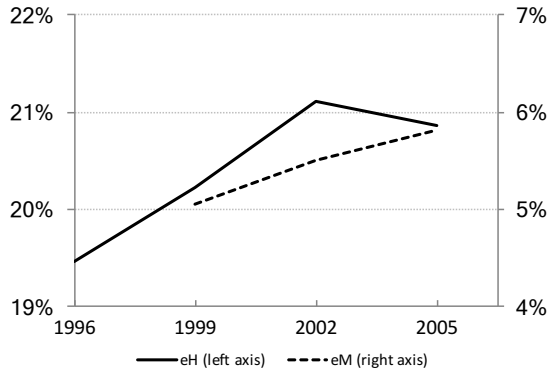
$$e_H = \frac{\text{persons in tertiary education (fte)}}{\left(\frac{1}{3}\right)\text{population of 18-29}} . \frac{\text{annual hours studied per student}}{\text{potential annual hours}} . \text{completion rate} \tag{4}$$

The calculation of the participation rate in persons reflects the assumption that the typical high ability individual has the talent to study at the tertiary level. We divide the total number of students in tertiary education (in full-time equivalents, fte) by the assumed total number of young individuals of high ability, i.e. one third of the population aged 18 to 29. If the number of students (in fte) in tertiary education in the data exceeds 33% of the population, we allot this surplus to medium ability individuals (e_M) who obtained a higher secondary degree and can also study at the tertiary level. Actual to potential annual hours follows from multiplying the ratio of actual to potential hours of study per week and the ratio of actual to potential weeks of study per year. The first part we set to 0.7. For the second part, we rely on the assumption that individuals study 42 out of 52 weeks. The completion rate is the fraction of students that is expected to graduate. It is set to 0.7, the average observed in Belgium during 1996-2007 (OECD, Education at a Glance 2000, 2002, 2004, 2006, 2007, 2009). By accounting for the fact that not all students also obtain their diploma, we try to better measure *effective* hours studied, i.e. time in education that - as in the model - effectively leads to the accumulation of relevant human capital.

Figure B.5 shows the evolution of our measure for e_H in the data in 1996-2007. Our measure for e_M is computed in the same way. But then the participation rate in persons counts all students in post-secondary non-tertiary education and the excess of students in tertiary education above 33% of the population of 18 to 29.

Data source: Participation rate in education in persons by age : OECD, Education and Skills, Students enrolled by age.

Figure B.5: Participation rate in education in hours (%, 1996-2007)



B.3 Pre-tax earnings ratios in Belgium

Data on relative earnings for Belgium are available from OECD Education at a Glance. We use the data for workers of age 25 to 64 during the calibration period (1996-2007). In line with our overall approach, we consider earnings of a worker without higher secondary education as representative for low ability individuals, and earnings of a worker with a higher secondary degree but no tertiary degree as representative for workers with medium ability. The earnings of a worker with a tertiary degree are assumed representative for workers with high ability. The relative wages of low versus high ability workers is 69%. The relative wage of low versus medium ability workers is 90%.

C Data on demography, fiscal policy and pensions

C.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 5a in the main text. 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 5b in the main text.

C.2 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 (Devereux et al., 2002). 1970-1981: 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 parameters: 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 public pension scheme cr_1 and cr_2 are 7.5% and 8.9% respectively (OECD Pensions at a Glance, 2013).

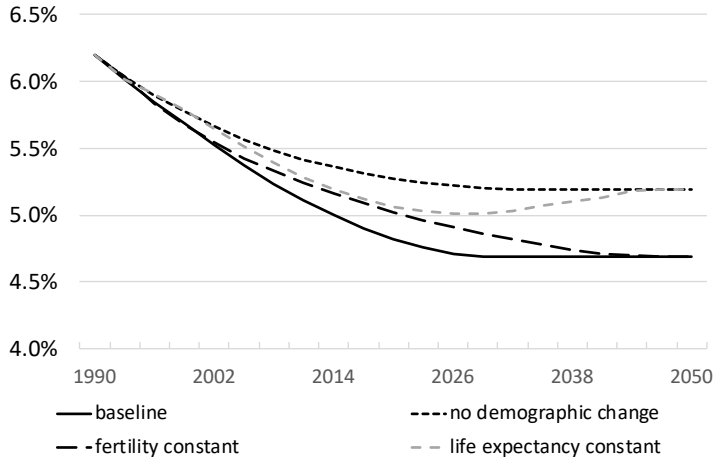
b: Gross unemployment benefit replacement rate for the low ability group
Data sources and description: OECD Database on Benefit Entitlements and Gross Replacement Rates for data going from 1961 to 2007. The reference earnings are 67% of average earnings. For 2008-2014, we extrapolate this data series 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: European Commission, AMECO, series UDGGL.

D Counterfactual world interest rate scenarios

D.1 World interest rate 'no demographic change' counterfactual (+0.5%-points)

Figure D.1: World real interest rates ($r_{ndc} = r_{baseline} + 0.5\%\text{-}points$)



D.2 Alternative world interest rate 'no demographic change' counterfactual (+1%-point)

Figure D.2: World real interest rates ($r_{ndc} = r_{baseline} + 1\%\text{-}point$)

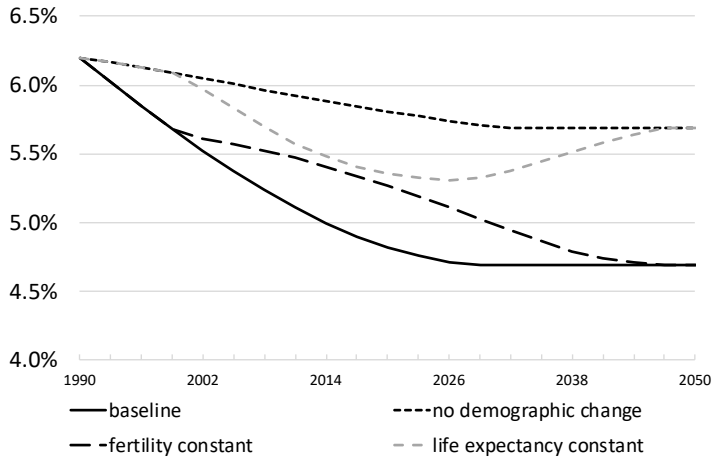
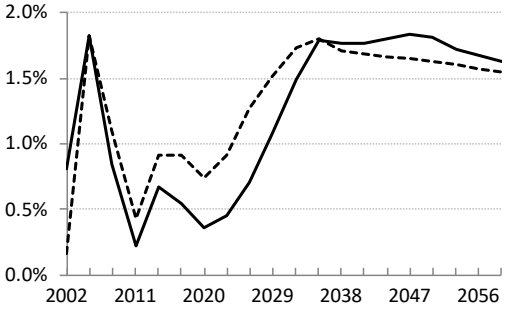
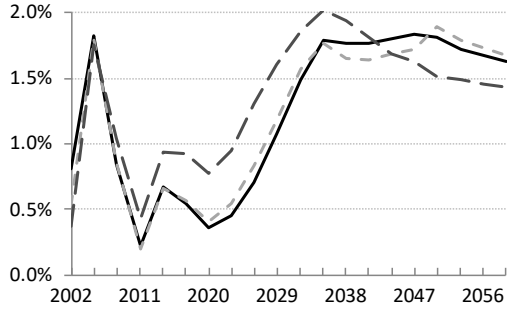


Figure D.3: Demographic change: macroeconomic effects ($r_{ndc} = r_{baseline} + 1\%\text{-}point$)

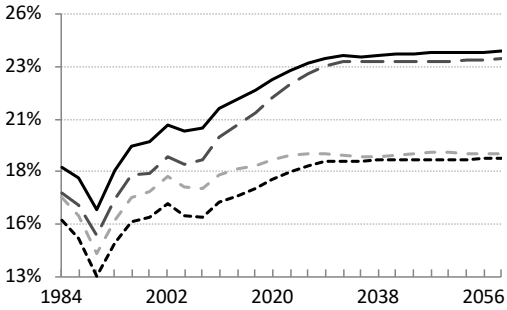
(a) Average annual per capita growth rate (baseline versus 'no demographic change')



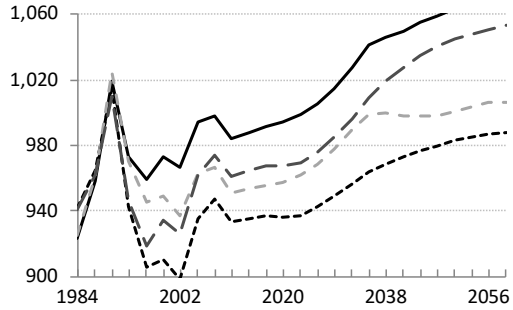
(b) Average annual per capita growth rate (baseline versus 'fertility constant' and 'life expectancy constant')



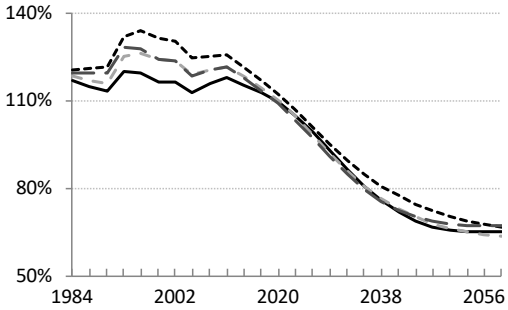
(c) Education rate (high ability)



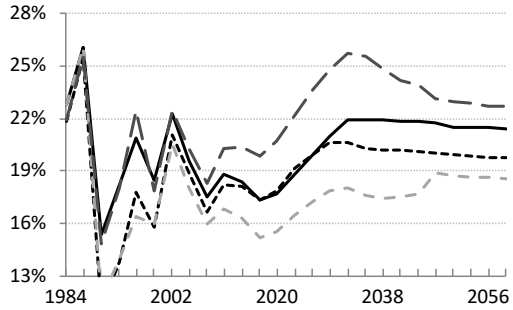
(d) Average annual hours worked per person at working age



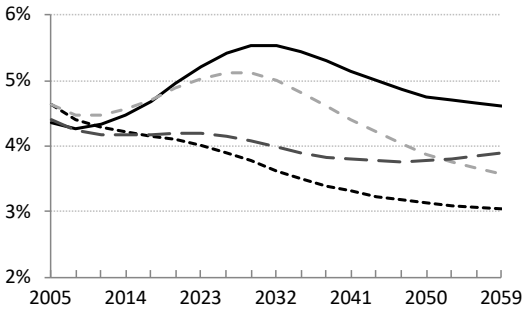
(e) Stock of non-human wealth (% of GDP)



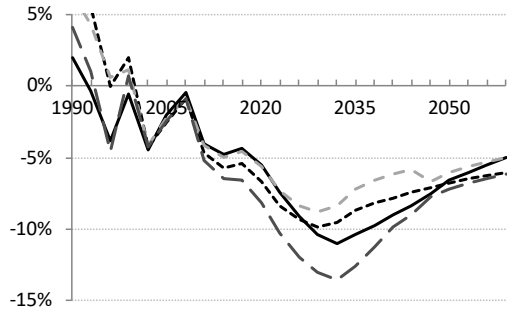
(f) Gross investment (% of GDP)

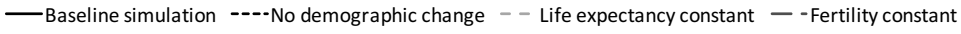


(g) Public pension expenditures (% of GDP)



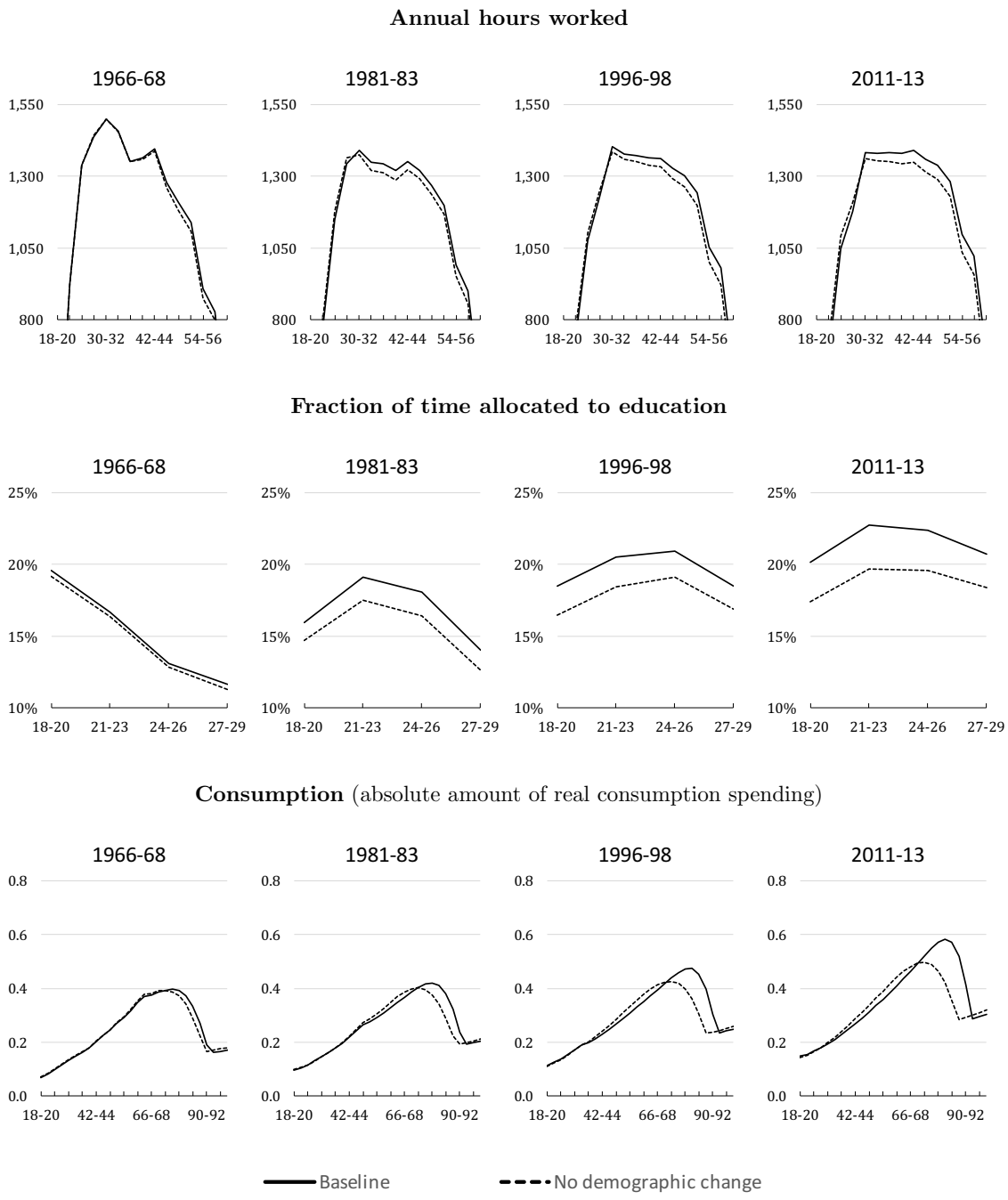
(h) Current account ($F_{t+1} - F_t$, % of GDP)





E Effects of demographic change at the level of individual cohorts

Figure E.1: Life-cycle profiles of the youngest generation (of high ability) in 1966, 1981, 1996 and 2011



Note: each panel of this figure shows the evolution of annual hours worked, education time or consumption over a representative individual's life. The horizontal axis represents the individual's age. We consider individuals who enter our model (at age 18) in 1966-68, 1981-83, 1996-98 and 2011-13. The full black line is our baseline simulation, the dotted line the 'no demographic change' counterfactual.

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