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OLD AGE TAKES ITS TOLL: LONG-RUN PROJECTIONS OF HEALTH-RELATED PUBLIC EXPENDITURE IN LUXEMBOURG

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Old age takes its toll: long-run projections of health-related public expenditure in Luxembourg[♣]

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Abstract: This paper simulates long-term trends in Luxembourg's public expenditure on healthcare and on long-term care. We combine population projections with micro-simulations of individuals' health status that account for their demographic, socio-economic characteristics and their childhood circumstances. Model equations estimated on data from the SHARE survey and from several branches of Social Security provide a rich framework to study policy-relevant applications. We simulate public expenditure on healthcare and long-term care under different scenarios to evaluate the separate contributions of population ageing, costs of producing health-related services, and the distribution of health status across age cohorts. Results suggest that rising per capita expenditure on healthcare will mostly result from production costs, while rising expenditure on long-term care will mostly reflect population ageing.

Keywords: Ageing, Dynamic micro-simulation, Healthcare, Health-related public expenditure, Health status, Long-term care, Luxembourg, SHARE.

JEL Classification: D3, H30, I10, I12.

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Non-technical summary

This paper simulates long-term trends in Luxembourg's public expenditure on healthcare and on long-term care. We combine official population projections with micro-simulations of individuals' health status that account for their demographic or socio-economic characteristics and their childhood circumstances. In our benchmark scenario, public expenditure on healthcare rises from 5.8% of GDP in 2020 (without pandemic effect) to 7% in 2070. Per capita public expenditure on healthcare rises from 5400 euros in 2020 to 9400 euros in 2070 (at 2020 prices). Population ageing explains more than a quarter of this increase, with rising costs of production accounting for the rest. Also in our benchmark scenario, public expenditure on long-term care rises from 0.7% of GDP in 2020 to 2.5% in 2070. Per capita expenditure on long-term care rises from 600 euros in 2020 to 3400 euros in 2070, while per beneficiary expenditure rises from 41700 to 76200 euros. Rising costs of production explain more than a third of the increase in per capita terms and two thirds of the increase in per beneficiary terms.

To obtain these results, we first extend the standard theoretical model of consumption to allow consumers' health-related behaviour to affect future health and expenditure. Second, we estimate model equations for Luxembourg using micro data on individuals from the Survey of Health, Ageing and Retirement in Europe (SHARE), as well as aggregate data from several branches of Social Security. Third, we simulate public health expenditure using long-term population projections from the European Commission and the GDP projections the Luxembourg Central Bank constructed on this basis. We simulate different scenarios to disentangle the role of population ageing, costs of producing health-related services, and the distribution of health status across age cohorts. Results suggest that rising per capita expenditure on healthcare will mostly result from production costs, while rising expenditure on long-term care will mostly reflect population ageing.

Our results are aligned with assessments by the OECD and by the European Commission, who anticipate that Luxembourg will experience the sharpest increase in ageing-related spending among EU countries. Although Luxembourg's Social Security system currently enjoys a comfortable financial situation, the projected increase in spending endangers its sustainability. While pensions, which are not studied here, would account for most of the increase, controlling the costs of healthcare and long-term care would help to limit the impact on public finances.

Since our model focuses on individual behaviour, it can serve for *ex-ante* evaluation of policies affecting individual decisions such as retirement age, savings rate, and health-related behaviour (e.g. physical exercise, smoking and drinking). Our simulations cover a very long horizon, so the traditional caveats apply. We assume constant preferences and moderate productivity growth in order to focus on population ageing and its likely impact on average health status.

Résumé non technique

Cet article simule les tendances à long terme de la dépense publique au Luxembourg en matière de soins de santé et de soins de longue durée. Nous combinons les projections démographiques officielles avec des micro-simulations qui déterminent l'état de santé des individus en tenant compte de leurs caractéristiques démographiques ou socio-économiques et des circonstances de leur enfance. Dans notre scénario de référence, la dépense publique en matière de santé passe de 5,8 % du PIB en 2020 (hors effet pandémique) à 7 % en 2070. La dépense par habitant passe de 5400 euros en 2020 à 9400 euros en 2070. Le vieillissement de la population explique plus d'un quart de cette augmentation, le reste étant attribuable à la hausse des coûts de production. Toujours dans notre scénario de référence, les dépenses publiques en soins de longue durée passent de 0,7 % du PIB en 2020 à 2,5 % en 2070. La dépense par habitant pour les soins de longue durée passe de 600 euros en 2020 à 3400 euros en 2070, tandis que les soins par bénéficiaire passent de 41700 à 76200 euros. La hausse des coûts de production explique plus d'un tiers de l'augmentation par habitant et les deux tiers de l'augmentation par bénéficiaire.

Pour obtenir ces résultats, nous modifions le modèle théorique standard de la consommation pour permettre que le comportement des consommateurs en matière de santé affecte leur état de santé futur ainsi que les dépenses associées. Ensuite, nous estimons les équations du modèle en utilisant des micro-données luxembourgeoises issues de l'Enquête sur la santé, le vieillissement et la retraite en Europe (SHARE), ainsi que des données agrégées provenant de plusieurs branches de la Sécurité Sociale. Enfin, nous simulons les dépenses publiques de santé à partir des projections démographiques à long terme publiées par la Commission européenne et des projections du PIB que la Banque centrale du Luxembourg construites sur cette base. Nous utilisons différents scénarios de simulation pour ventiler la contribution du vieillissement de la population, celle des coûts de production des services de santé et celle de l'état de santé des différentes cohortes d'âge. Les résultats suggèrent que l'augmentation des dépenses par habitant en matière de soins de santé est principalement déterminée par les coûts de production, tandis que l'augmentation des dépenses liées aux soins de longue durée reflète davantage le vieillissement de la population.

Nos résultats sont cohérents avec les évaluations de l'OCDE et de la Commission européenne, selon lesquelles le Luxembourg connaîtra la plus forte augmentation des dépenses liées au vieillissement parmi les pays de l'UE. Bien que le système de Sécurité Sociale luxembourgeois bénéficie actuellement d'une situation financière confortable, cette augmentation prévisible des dépenses met en danger sa pérennité. Alors que les retraites, qui ne sont pas étudiées ici, représenteraient l'essentiel de l'augmentation des dépenses à l'horizon 2070, la maîtrise des coûts liés aux soins de santé et aux soins de longue durée pourrait contribuer à limiter l'impact sur les finances publiques.

Puisque notre modèle se concentre sur le comportement individuel, il peut servir pour évaluer *ex-ante* des politiques publiques qui affectent des décisions individuelles, telles que l'âge de la retraite, le taux d'épargne et les comportements liés à la santé (par exemple, l'activité physique ou la consommation de tabac et d'alcool). Comme nos simulations couvrent un horizon très long, il faut tenir compte de leurs limitations. En particulier, nous supposons des préférences constantes et une progression modérée de la productivité, afin de nous concentrer sur le vieillissement de la population et son impact probable sur l'état de santé moyen dans le futur.

1. Introduction

This paper studies how public expenditure on healthcare and long-term care responds to individuals' evolving health status under alternative demographic projections. More precisely, we extend a theoretical model of optimal intertemporal consumption to simulate trends of health-related public expenditure that depend on individuals' health status and health-related behaviour as well as their demographic, socio-economic characteristics and childhood circumstances.

Models of optimal intertemporal consumption are often used to study the impact of health status and other precautionary motives on saving behaviour. For instance, De Nardi et al. (2006) estimate and simulate a model based on Deaton (1991) to evaluate the role of health status and insurance on the consumption and saving behaviour of elderly singles in the United States. De Nardi et al. (2009) follow a similar approach to disentangle the effects of life expectancy on old age saving from other determinants, including medical expenditures, which also vary by gender, age, health status, and income. More recently, Ameriks et al. (2020) estimate the relative importance of bequest and precautionary motives for late-in-life savings.

In this paper, we adapt this standard theoretical framework to better account for the specificities of the healthcare sector in Luxembourg, which differs fundamentally from the United States system studied by the articles cited above. Luxembourg provides wide access to high quality public healthcare but its system is among the most costly in Europe (OECD, 2017; European Commission, 2020). The major challenge it faces is from demographic change, which might endanger the sustainability of the social protection system. In particular, the age-related expenditure ratio is projected to double by 2070, placing Luxembourg well above other countries in the European Union (AWG, 2021).

Policies to meet this challenge need to affect individual decisions such as retirement age, saving rate, and health-related behaviour (e.g. physical activity, smoking and drinking habits). To evaluate these policies, we developed a simulation tool for Luxembourg that allows individual economic decisions and health-related behaviour to affect public expenditure on healthcare and long-term care over long horizons. First, we extend the standard theoretical model to allow consumers' health-related behaviour to affect current income and working time, as well as future health and expenditure. Second, we fit the model to Luxembourg by estimating most equations and calibrating the remainder. Finally, we use the resulting empirical model for a dynamic simulation exercise. The present version of this simulation tool focusses on individuals' health and health-related behaviour and its impact on public expenditure. The study of consumption/saving paths as well as labour supply and retirement decisions is left for future research.

The richly specified model equations provide meaningful applications. In particular, we can decompose changes in aggregate health-related public expenditure (i.e., healthcare and long-term care) into contributions from different individual characteristics, such as demographic and socio-economic conditions as well as diagnosed diseases. In principle, the model can simulate *what if* scenarios to evaluate the impact on specific diseases from new medical treatments, prevention or other health-related policies, and can map these effects to public expenditure projections. To our knowledge, this is the only simulation tool to allow such analyses for Luxembourg.

To estimate the model equations, we combine two types of data. First, micro data on individuals from the Survey of Health, Ageing and Retirement in Europe (SHARE). Second, aggregate data from several branches of the Luxembourg Social Security system. We base the empirical application on long-term demographic and macroeconomic projections from the European Commission and the Central Bank of Luxembourg. To assess the long-run effects of different determinants of health-related public expenditure, we design several health-related scenarios. These serve to disentangle the role of demography, costs of producing health-related services, and the distribution of health status across age cohorts. Results identify production costs as the main driver of per capita healthcare expenditure, while population ageing appears more relevant for public expenditure on long-term care.

To facilitate the reading of the paper, the theoretical model is presented in Appendix A. The rest of the paper is organized as follows. Section 2 describes the data and its sources. Section 3 discusses estimation strategy and calibration. Section 4 explains how we aggregate health-related public expenditure across individuals. Section 5 describes our simulation approach and the implemented scenarios, and presents the results. Section 6 concludes.

2. The data

To estimate and calibrate the parameters of the model for Luxembourg, we use data from several sources. First, we use Luxembourg data from the Survey of Health, Ageing and Retirement in Europe to estimate parameters such as the individual health status, health-related behaviour, demographic characteristics, socio-economic conditions, and childhood circumstances. Second, we calibrate health-related activities and healthcare costs using data from several branches of Luxembourg's Social Security system. Third, for long-term simulations, we rely on the demographic projections published by the European Commission and long-term macroeconomic projections for Luxembourg published by the Central Bank.

2.1. Survey of Health, Ageing and Retirement in Europe

The Survey of Health, Ageing and Retirement in Europe (SHARE) is a multidisciplinary, cross-national panel survey. It collects data on individuals aged 50 years or older and their partners (of whatever age) through more than seven hundred questions on health (e.g. physical health, mental health, health behaviour, healthcare), socio-economic conditions (e.g. living conditions, employment status, income, pensions), and social and family networks (e.g. intergenerational support, volunteering).[3] SHARE is unique in covering a wide range of health-related variables (O'Donnell, 2009), which is a key advantage to estimate the parameters of our model. In particular, we use data from Waves 5 and 6, Release 7.1.0 (Börsch-Supan, 2018) collected in Luxembourg in 2013 and 2015, respectively.[4]

SHARE results for Luxembourg are representative of the resident population, by gender and age. However, it does not cover the population living in specialized institutions or nursing homes, nor does it cover non-residents who cross the border every day to work in Luxembourg and therefore benefit from the Luxembourg Social Security system. The sample includes 1563 respondents. Individual sample weights ensure that results are representative of the target population. However, they do not consider the distribution of different diseases across the population.

2.2. Luxembourg Social Security

To calibrate the model, we use data from the Luxembourg Ministry of Social Security. Aggregate data from the National Health Fund (*Caisse Nationale de Santé*, or CNS) covering 2013-2016 provides detail by gender, age, and disease on the number of medical visits to general practitioners and to specialists, as well as the number of nights spent in hospital.

[3] See Börsch-Supan et al. (2013) for a detailed description of SHARE.
[4] The more recent wave 7 of SHARE mainly focuses on people's life history, omitting many variables needed for our analysis.

Appendix B describes other publicly available data sources used to calibrate individual expenditure on healthcare and the algorithm that identifies individuals needing long-term care.

2.3. European Commission and Luxembourg Central Bank

We rely on Eurostat (2020) population projections reflecting a set of assumptions on future age-specific fertility rates, age-specific mortality rates, and international net migration levels. For the purpose of our simulation, we use the EUROPOP2019 baseline scenario. To build indicators of longevity, we also use Eurostat projections on the evolution of life expectancy by age and gender.[5]

To project expenditure-to-GDP ratios in the long-term (to 2070), we use real GDP projections for Luxembourg published by the Central Bank using the LOLA model (Marchiori and Pierrard, 2015; Garcia Sanchez et al., 2021). These are consistent with the EUROPOP2019 baseline demographic projections.

3. Estimation strategy and calibration

Since this paper focuses on how individuals' characteristics affect aggregate expenditure on healthcare and long-term care, the empirical analysis concentrates on estimating and calibrating the parameters in Eq. (A.2) to (A.6), and (A.8) of Appendix A.

3.1. A measure of health status

To measure the health status of each individual, we follow the multidimensional approach in Pi Alperin (2016), which uses fuzzy set theory to aggregate several health conditions reflecting various aspects of mental and physical health into a single indicator of health status. Each health condition itself aggregates several health variables (included in the vector of diseases s_d).

Table 1: Components of the health status indicator[6]

Dimensions		**Health conditions (*d*)**	**Health variables (*i* in Φ)**
Health status	Mental health	Depression	Depression, pessimism, suicidal feelings, guilt, sleep, interest, irritability, appetite, fatigue, concentration, enjoyment, tearfulness
		Memory	Day, week, month, year
		Orientation	Ten words 1, ten words 2
	Physical health	Permanent conditions	Hypertension, high cholesterol, diabetes, pneumonia, Parkinson, Alzheimer, anxiety, rheumatism, arthrosis, kidney problems
		Non-permanent conditions	Heart attacks, strokes, cancers, ulcers, cataracts, femur fractures
		Limitation on activities 1	Dressing, movement, bathing, eating, bed, toilet, map, meal, shop, telephone, medicines, work, money, cleaning
		Limitation on activities 2	Walking, sitting, chairs, stairs, stairs 2, stooping, arms, objects, weights, coins
		Eyesight	Farsighted, near-sighted
		Hearing	Hearing with or without hearing aid

[5] Available at https://ec.europa.eu/eurostat/web/main/data/database.

[6] See Appendix C for the definitions of health conditions using SHARE health variables.

We aggregate sixty-one health variables into nine health conditions that we then aggregate into a single health status indicator for each individual. The sixty-one health variables include diagnosed diseases, limitations in daily life activities, symptoms of depression and measures of memory (Table 1 provides an overview of the health variables included in each health condition). The health status indicator is calculated as a simple average of the health conditions. Parameters γ_d in Eq. (A.2) are set to equal weights summing to one. This assumes that each condition is equally important for health status.[7] In addition to the overall health status indicator, we can compute separate components for mental health and for physical health.[8]

3.2. Individual characteristics

The focus of our model is on how individual characteristics influence health-related behaviour, which in turn affects individual health status and expenditure on healthcare. In particular, we consider four aspects of health-related behaviour: smoking, alcohol consumption, physical exercise and obesity. These are modelled using three different vectors of individual characteristics: demographic characteristics, childhood circumstances and socio-economic conditions. Table 2 presents the components of these three vectors used when estimating the model equations.

Table 2: Individual characteristics

Vector	**Components**
Demographic (DEM)	Age, gender, and household size
Socio-economic conditions (SEC)	Educational attainment, household equivalent disposable income, workforce participation and years of contribution to the pension system
Childhood circumstances (C)	Country of birth, parents' longevity, and financial situation during childhood
Multimorbidity (O)	Diseases such as diabetes, high cholesterol, which are risk factors for other diseases included in the analysis
Health status (*m*)	Mental and physical health

Some of these variables and vectors need further explanation:

- Household size records the number of individuals living in the same household regardless of family ties.
- Workforce participation is a binary variable indicating whether the individual is economically active.
- Educational attainment reflects the highest level reached according to the 1997 version of the International Standard Classification of Education (ISCED). Individuals with higher education are those with a first or second stage of tertiary education (corresponding to ISCED 1997 categories 5–6). Individuals with lower education are those with upper or post-secondary education or any level below (corresponding to ISCED 1997 categories 0–4).
- Financial situation during childhood identifies individuals who report they grew up (from birth to age 15) in a poor family or one whose financial situation was poor at one time.

[7] Alternative weighting schemes change the distribution of health status across the population. Nevertheless, main conclusions are unaffected.

[8] The indicators are computed using the user-made Stata command 'mdepriv' (see Pi Alperin and Van Kerm, 2014).

- Parents' longevity proxies for parental health, following Jusot et al. (2013). SHARE survey participants report whether their parents are still alive at the time of the survey or their parents' age at death.
- Multimorbidity reflects the fact that for some diseases, the probability of being diagnosed depends on having concomitant diseases (i.e., vector O may be empty or include several diseases).

3.3. Modelling diseases

The function governing the probability of having each disease (Eq. A.8 in appendix A) depends on individuals' health-related behaviour and health status, which are both likely influenced by other individual characteristics. Therefore, to estimate the parameters in Eq. (A.8), we adopt a three-step procedure following Trannoy et al. (2010) and Lazar (2013)

3.3.1. First step: health-related behaviour and general health status

We specify health-related behaviour as a function of age, gender and other individual characteristics. In the following system of equations, we consider four types of non-mutually exclusive health-related behaviour s (smoking, alcohol drinking, physical exercise and obesity), with $HB^s \in \{0,1\}$:

$$Pr\left(HB^s = 1 \,\middle|\, DEM_{a,g}, SEC_{a,g}, C\right) = F_s(-u_t^s < DEM_t\beta_1^s + SEC_t\beta_{21}^s + C\beta_3^s + U^s\beta_u^s - \zeta^s), \quad (1)$$

$$s \in \{Smoke, Alcohol, PhEx, Obesity\},$$

where $PhEX$ refers to *physical exercise*. For each s in Eq. (1), vectors DEM, SEC and C include the same variables (see Table 2). However, following Trannoy et al. (2010), the matrix U^s varies across equations and incorporates estimated residuals from other equations in the system following a recursive order:

$$\begin{aligned} U^{Alcohol} &= [\hat{u}^{Smoke}] \\ U^{PhEx} &= [\hat{u}^{Smoke}, \hat{u}^{Alcohol}] \\ U^{Obesity} &= [\hat{u}^{Smoke}, \hat{u}^{Alcohol}, \hat{u}^{PhEx}], \end{aligned}$$

where, $\hat{u}^s$ is the deviance residual obtained from probit regressions of Eq. (1) for each s among smoking, alcohol drinking, physical exercise and obesity. If the exogeneity assumptions implied by the above recursive structure are verified in the data, the approach would provide consistent estimates of the effect of individual characteristics (parameters $(\beta_1^s, \beta_2^s, \beta_3^s)$ in Eq. (1)).

Then, based on a linear regression of the logit transform of the health indicator m, we estimate the parameters β^m in the following equation:

$$m^* = DEM_t\beta_1^m + SEC_t\beta_2^m + C\beta_3^m + U^m\beta_u^m + u^m, \quad (2)$$

where, m^* is the logistic transformation of the health status indicator and vectors DEM, SEC and C are the same as in Eq. (1). However, matrix U^m includes $\hat{u}^{Smoke}, \hat{u}^{Alcohol}, \hat{u}^{PhEx}$ and $\hat{u}^{Obesity}$ as estimated in Eq. (1).

3.3.2. Second step: conditional probability of having each disease

In the second step, we estimate probit regressions for each of the sixty-one diseases included in the health status indicator (all $i \in \Phi$ in Eq. (A.8)) to obtain the probability of being affected by each disease for every individual, conditioning on his/her individual characteristics. Thus, we replace the variables hb and m in Eq. (A.8) by, respectively, matrix U^m in Eq. (2) and $\hat{u}^m$, the estimated residual from Eq. (2). This approach should provide consistent estimates of the parameters in Eq. (A.8) while accounting for inter-relationships between these different aspects of health-related behaviour. However, as we include a constant among the explanatory variables in the empirical specification of Eq. (A.8), thresholds ζ^i cannot be identified in the probit regressions.

3.3.3. Third step: threshold estimation

In the third step, we compute the threshold $\hat{\zeta}^i$ for each disease $i \in \Phi$, using a grid search algorithm that minimizes a linear combination of classification errors.[9] From the estimated Eq. (A.8), for each disease i and each individual we obtain the sum of the linear prediction and the deviance residual $\hat{u}^i$. Each candidate value of the threshold $\hat{\zeta}^i$ serves to classify the population into those who have the disease (their predicted probability exceeds the candidate threshold) and those who do not (their predicted probability is below the candidate threshold). The parameter $\hat{\zeta}^i$ is then set to minimize the following loss function:

$$L(\zeta^i) = 0.5 \cdot \left(1 - TPR(\zeta^i)\right) + 0.5 \cdot FPR(\zeta^i), \quad (3)$$

where TPR is the *true positive rate* and FPR is the *false positive rate*[10] obtained by comparing the resulting classification to the one actually reported by participants in the survey.

3.4. Working status

Equations (A.3) and (A.4) in Appendix A account for the endogenous relationship between general health status and work force participation. While participation in the labour force requires a minimum level of health, the type of work performed can affect individuals' current and future health and determines their capacity to continue performing the same type of work. Modelling such an endogenous relationship is challenging whether one uses a self-assessed health indicator or an objective measure of individual health status (Bound, 1991). Self-assessed health measures can over-estimate the role of health in work decisions because of justification bias (Lindeboom and Kerkhofs, 2009). On the other hand, objective health measures might be poorly correlated with work force participation decisions. In our model, we follow the traditional approach of Stern (1989) and use a measure of general health status (defined in Section 3.1), which includes several features of mental and physical health that can prevent individuals from working and therefore correlate with the individual decision to participate in the workforce.

To estimate the parameters in Eq. (A.3) and (A.4), we employ a multinomial probit model of the current job situation, represented by the SHARE variable CJS, which has five categories (employed, unemployed, early-retirement, disabled and retired). We use the category employed as the reference group. Following the same approach as in Section 3.3.2, general health status is represented by the predicted residual from Eq. (2) $\hat{u}^m$, and the thresholds $\hat{\zeta}^k$ in (A.4) are computed with a grid search algorithm.

[9] This 'signals approach' or 'signalling approach' (Detken et al., 2014) is widely used in medical sciences to calibrate diagnostic tests (Swets, 1979, Hanley and McNeil, 1982).

[10] For definitions of these concepts, see Detken et al. (2014).

3.5. Survival probability

The survival probability of individuals varies across gender, age and time, as we constrain the population to follow the baseline scenario of EUROPOP2019 projections. For each year t, the probability of survival until $t+1$ for an individual of gender g, age a and general health status m is:

$$sp_{a,g,m}^{t} = \Pr\left(1 + m_{a,g} - \frac{N_{a+1,g}^{t+1}}{n_{a,g}^{t}} < \epsilon\right) \tag{4}$$

where, ϵ is random draw from a uniform distribution in the interval $[0,1]$, $N_{a+1,g}^{t+1}$ is the number of individuals of gender g and age $a+1$ who are alive in year $t+1$ (according to Luxembourg's population projections), and $n_{a,g}^{t}$ is the number of individuals of gender g and age a in the target population. Therefore, Eq. (4) implies that an individual's survival probability increases with his/her health condition and with the projected growth of his/her population subgroup.

4. Health-related public expenditure

In the theoretical model (Appendix A), we assume that health-related expenditure per individual ($hc_{a,g,m}(\pi_t)$) is a deterministic function of health status, gender, age, and public insurance benefits with risk only affecting individuals' health status. Therefore, expenditure is known once shocks to health status have been observed. In the following, we distinguish healthcare and long-term care expenditure, which are largely covered by public insurance in Luxembourg.

4.1. Healthcare

The Luxembourg Social Security system includes health and maternity insurance, which is managed by the CNS and provides benefits both in-kind and in-cash. In-kind benefits include, among other, medical and dental care, care provided by health professionals, treatment in and out of hospital, laboratory analysis, medical imaging, physiotherapy, medication, ancillary products, rehabilitation, therapeutic and convalescent cures, travel and transportation costs, and palliative care. In-kind benefits represent 95.6% of total public expenditure by health and maternity insurance (CNS, 2017). In-cash benefits include full salary replacement in the event of illness or during maternity leave.

We use a two-step procedure to calculate total public expenditure on healthcare. In the first step, we split up total in-kind benefits across a set of diseases. This step, however, only covers part of public expenditure on healthcare. First, we neglect in-cash benefits. Second, we neglect healthcare expenditure on residents younger than 50 and on non-residents working in Luxembourg, since these groups are not covered by the SHARE survey. Third, we neglect healthcare expenditure on diseases omitted by the SHARE survey (see Appendix D) and we only consider a limited number of generic medical treatments. Finally, we neglect some in-hospital treatments at this step.

To address these limitations, in a second step, we "gross up" public expenditure on healthcare to cover the entire population insured in Luxembourg (both residents and non-residents). We still link total public expenditure on healthcare to individual characteristics (e.g. health status, socio-economic conditions). This will allow us to evaluate total public expenditure on healthcare in scenarios tracking the evolution of individual characteristics under different assumptions. For this purpose, we implement an algorithm that estimates average expenditure by age and gender for the entire insured population.[11]

4.2. Long-term care

Long-term care insurance, another branch of the Luxembourg Social Security system, partially covers the costs of care for those who need everyday assistance. This includes care in the areas of personal hygiene, elimination, nutrition, dressing, and mobility (AEV, from the French *Actes Essentiels de la Vie*). Long-term care insurance benefits individuals who are at least partially invalid, a condition resulting from chronic disease and either irreversible or persisting over six months. All insured persons, and their family members, can benefit regardless of their income level, as long as they meet the Social Security criteria to be declared *dependent*.

To link public expenditure on long-term care to individual health status, we develop an algorithm that mimics the administration's evaluation procedure, adapting it to our model of diseases and limitations in daily activities. Appendix E describes this algorithm in detail.

5. Simulation results

We simulate the evolution of the population using 5-years intervals over the period from 2015 to 2070. Individuals' socio-economic situation and health status evolve according to the rules presented in Section 3 and Appendix A. At the beginning of each interval, we draw randomly from the estimated distributions and calculate public expenditure on healthcare and long-term care for each individual. Then, we "gross up" results to cover the part of the population not covered by the simulations. Finally, we use equation (4) to generate individual probabilities of surviving into the next period, subject to the aggregate result matching the underlying demographic projections.

Below, we present three *what if* scenarios to evaluate the impact on public expenditure from changes in the size and age structure of the population, as well as the evolution of individual health status, household income and costs of healthcare provision. In all simulations, population growth and age structure match the baseline scenario of the EUROPOP2019 projections. All scenarios also assume *constant prevalence*[12] for the sixty-one diseases and limitations considered, meaning that over the whole simulation horizon these affect the same share of the population as observed in the 2015 SHARE survey.[13]

The literature on population ageing focuses on two hypotheses concerning the future expenditure on health-related services. According to the *morbidity expansion* hypothesis (Vebrugge, 1984; Gruenberg, 1977) life expectancy will increase but the population will suffer poor health throughout the additional years of life. This hypothesis attributes the increase in life expectancy to a reduction in mortality associated with disease, rather than to a reduction in the prevalence of disease. As a result, population ageing leads to higher expenditure on healthcare and long-term care. Instead, the *morbidity compression* hypothesis (Fries, 1980) assumes that individuals will only suffer poor health in the last years of life. In other words, the elderly population would enjoy good health through most of the additional years of life.

[11] Appendix D describes in detail how we calculate healthcare insurance expenditure.

[12] Prevalence is measured by the share of population affected by a given disease at a given time or over a given period.

[13] As SHARE is not designed to be representative by disease, we controlled the prevalence of diseases observed in SHARE 2015 with different European epidemiological studies (see Appendix G).

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Our *benchmark scenario* assumes that the unit cost of healthcare provision increases at the same rate as real GDP *per capita*. The Ageing Working Group (AWG, 2021) projections implicitly adopt this assumption, as they have real wages increase at the same rate as real GDP per capita. This assumption seems particularly plausible for the health sector, given its high level of labour intensity in production. We assume that long-run annual growth in Luxembourg will be 0.73%, consistent with projections by Garcia Sanchez et al. (2021) using the LOLA model. Finally, Eq. (4) serves to calculate each individual's probability of survival into the next period, which depends on his or her health status.

Our second scenario (*morbidity compression*) only differs from the benchmark by breaking the link between an individual's general health status and his/her survival probability. Instead, survival becomes a function of age and gender only. In this scenario, Eq. (4) is simplified to:

$$sp_{a,g}^{t} = \Pr\left(1 - \frac{N_{a+5,g}^{t+5}}{n_{a,g}^{t}} < \epsilon\right). \quad (5)$$

This means that some individuals may live longer in relatively poor health. This leads to a more pessimistic scenario than the benchmark, in the sense that at the individual level ageing will raise health-related expenditure. However, the constant prevalence assumption generates a compression of morbidity. Since those individuals who reach old age will suffer worse health than in the benchmark, younger individuals will tend to enjoy better health than in the benchmark. Depending on the age structure of the population, this transfer of health from the old to the young may lead to lower total public expenditure than in the benchmark. Therefore, the comparison with the benchmark allows us to evaluate the impact of the morbidity compression hypothesis on health-related expenditure.

Our third scenario (*constant unit cost*) deviates from the benchmark in assuming that healthcare and long-term care production costs do not increase with per capita GDP, but remain constant in real terms. This 'optimistic' scenario evaluates whether technical progress and better management in the health sector could limit the impact of population ageing on health-related public expenditure.

5.1. Public expenditure on healthcare

Table 3 compares the projected evolution of public expenditure on healthcare between 2020 and 2070. These results, however, do not account for the substantial rise in 2020 expenditure due to the Covid-19 pandemic, which should not affect long-run trends of public expenditure on healthcare, or for the associated economic recession. Comparing results across different scenarios helps to identify the main drivers of the projected increase: unit costs, population growth, ageing and health status.

In the **benchmark**, total expenditure is expected to increase by 119.1% between 2020 and 2070, and per capita expenditure by 74.2%. This corresponds to an annual growth rate of 1.58%, well above the real GDP growth rate of 1.2%. Therefore, the share of total expenditure in GDP would rise from 5.8 to 7 percentage points. This is mainly driven by the increase in the unit cost of healthcare provision[14] as well as by changes in the health status of the population. The other two scenarios help to disentangle these factors.

In the **morbidity compression scenario**, total expenditure increases by 120.6% between 2020 and 2070 with annual growth rate of 1.59%. However, total expenditure in 2020 is lower than in the

[14] In the benchmark, the unit cost of healthcare provision increases at the same rate as real GDP per capita. For 2020, however, we assume costs remained at 2019 levels.

benchmark, as it is in all simulated periods.[15] This is because the constant prevalence assumption combines with non-conditional survival probability to compress morbidity and concentrate poor health among the oldest individuals, who represent the smallest population group. Since the benchmark scenario links survival probability to individual health status, it distributes unhealthy individuals more evenly across ages. Therefore, comparing these two scenarios provides an estimate of the financial savings associated with the morbidity compression hypothesis. The difference between scenarios is 0.06% of GDP, suggesting this assumption has only a limited impact on total healthcare expenditure.

Table 3: Public expenditure on healthcare between 2020 and 2070

Scenario		Projections							Change
		2020	**2025**	**2030**	**2040**	**2050**	**2060**	**2070**	**2020-2070**
Benchmark	Expenditure[(a)]	3395.2	3826.7	4234.4	5121.5	6014.9	6771.1	7437.8	119.1%
	% of GDP	5.8	5.5	5.7	6.0	6.4	6.5	7.0	1.2 ppts
	per capita[(b)]	5.4	5.8	6.1	6.9	7.8	8.6	9.4	74.2%
Morbidity compression	Expenditure[(a)]	3344.4	3768.1	4176.0	5085.9	5959.2	6688.9	7376.4	120.6%
	% of GDP	5.7	5.4	5.6	6.0	6.4	6.4	6.9	1.2 ppts
	per capita[(b)]	5.3	5.7	6.0	6.9	7.7	8.5	9.4	75.4%
Constant unit cost	Expenditure[(a)]	3395.2	3688.9	3934.8	4422.5	4826.6	5049.0	5153.7	51.8%
	% of GDP	5.8	5.3	5.3	5.2	5.2	4.9	4.8	-0.9 ppts
	per capita[(b)]	5.4	5.6	5.7	6.0	6.3	6.4	6.5	20.7%

[(a)] Million euros [(b)] Thousand euros per capita
Source: own calculations and BCL's long-term GDP projections.

In the **constant unit cost scenario**, total expenditure increases by only 51.8% between 2020 and 2070. This is entirely due to the effects of population growth and ageing, because the unit cost of healthcare services remains constant at the 2019 level. *Per capita* expenditure increases 21%, reflecting the constant prevalence assumption, which raises the share of individuals who suffer several chronic conditions simultaneously, as would be expected in an ageing population. Finally, the share of aggregate healthcare expenditure in GDP actually declines, since expenditure grows 0.84% per year in this scenario, while GDP grows 1.2% per year.

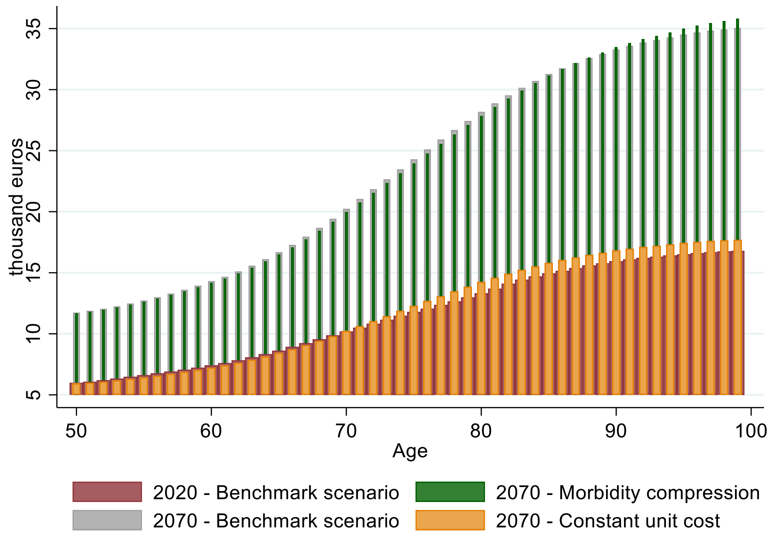
Comparing scenarios at the 2070 horizon, population ageing explains an increase of 1100 euros per capita (constant unit cost scenario) and rising costs of healthcare provision explain an increase of 2900 euros per capita (difference between benchmark and constant unit cost scenarios). The morbidity compression would not have a substantial effect, only adding 78 euros per capita.

Figure 1 depicts average healthcare expenditure by age in the different scenarios. All three scenarios assume constant prevalence, so the only factors that could explain differences are the unit cost of

[15] The percentage difference in total expenditure compared to the benchmark decreases from 1.4% in 2020 to 0.9% in 2070; these values are small but statistically significant.

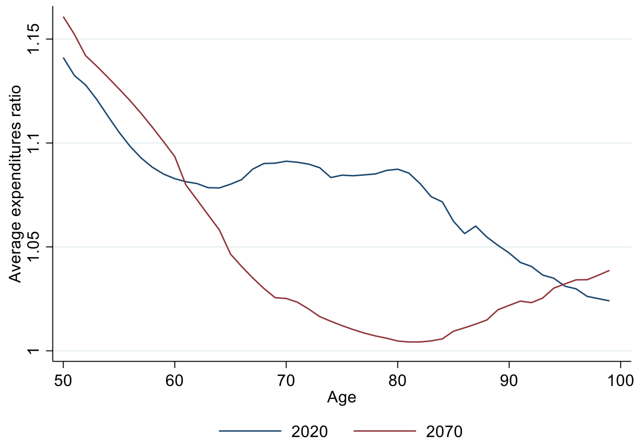
healthcare provision and the distribution of health across individuals of different ages. In all scenarios, average healthcare expenditure increases with age, reflecting poorer health among the elderly.

Figure 1: Healthcare, average expenditure by age



Source: Own calculations.

Figure 2 : Gender gap in average expenditure on healthcare, by age – Benchmark scenario



Source: Own calculations.

In the benchmark, average expenditure on healthcare more than doubles between 2020 (brown bars) and 2070 (grey bars). This mostly reflects the evolution of unit costs of healthcare provision. In the constant unit cost scenario[16] (orange bars), there are only limited changes between 2020 (this year is identical across scenarios) and 2070. The constant prevalence assumption implies that the projected demographic changes over the next fifty years will modify the distribution of health across ages, with young individuals enjoying better health and older individuals suffering worse health. This is visible in Figure 1, since average healthcare expenditure on individuals older than 75 years increases significantly from 2020 to 2070.

[16] The benchmark and the constant unit cost scenarios only differ in the evolution of unit costs of producing healthcare services (see Section 5).

In the morbidity compression scenario (green bars), individuals between 65 and 85 enjoy better health in 2070 than in the benchmark, while individuals above 88 suffer poorer health.[17] According to standard Student-t tests, differences in average healthcare expenditure by age are statistically significant,[18] but they do not lead to substantial differences in aggregate healthcare expenditure (see Table 3). This results directly from the definition of the morbidity compression scenario.

Figure 2 depicts the gender gap in average public expenditure on healthcare. It shows the ratio of average expenditure on men to that on women at different ages. The blue line refers to the situation in 2020 and the maroon line to the situation in 2070 (both in the benchmark scenario). In both cases, healthcare expenditure for men is above that for women at all ages. In 2020, the gender gap decreases with age but stabilizes around 9% for those between 60 and 80 years old. In 2070, the gender gap almost closes for those 80 years old.[19]

5.2. Public expenditure on long-term care

To identify potential beneficiaries of long-term care, we implement an algorithm mimicking current procedures in public administration (see Appendix E). This distinguishes those receiving benefits in-kind, benefits in-cash or both. It also distinguishes beneficiaries living in nursing homes from those receiving aid at home. According to 2017 expenditure on long-term care reported by the General Social Security Inspectorate (IGSS), our estimations fully cover expenditure on residents aged 50 or more and cover 96.5% of expenditure on all beneficiaries. In addition, our model accurately reproduces the distribution of expenditure across ages and gender as reported in IGSS (2020).

Table 4 reports the projected evolution of public expenditure on long-term care between 2020 and 2070. In the **benchmark**, total expenditure is expected to increase by 568.5% (3.87% annual growth rate) and the number of beneficiaries by 265%. The latter result is remarkably close to the 282% increase in the population aged 80 and over in the EUROPOP2019 baseline projection. While per capita expenditure rises by 431.5%, expenditure per beneficiary increases only by 83%, indicating substantial population ageing. As a share of GDP, total expenditure rises from 0.7 to 2.5 percentage points, which will require a substantial adjustment of public finances. Expenditure rises rapidly to 2.0% of GDP in 2050, after which it grows only slightly faster than GDP.

In the **morbidity compression scenario**, total long-term care expenditure increases by 352% (3.06% annual growth rate), less than in the benchmark. In 2020 and 2025, expenditure rises above the level in the benchmark, because the number of beneficiaries is also higher. Beyond 2025, the number of beneficiaries declines compared to the benchmark. Expenditure rises to 2.4% of GDP in 2070, 0.1 percentage points below its level in the benchmark.

These aggregate results may seem counterintuitive. Since the morbidity compression scenario concentrates poor health among the elderly, we would expect them to suffer more limitations in daily life activities, leading to higher expenditure on long-term care. However, only expenditure per beneficiary is higher than in the benchmark scenario. The disaggregated analysis below provides better insight into these results.

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[17] The benchmark and the morbidity compression scenarios have the same evolution of the unitary cost of the healthcare services production as well as expected demographic changes but differ in the distribution of the population health status (see Section 5).

[18] This treats simulated data as if it were actually observed, implicitly assuming coefficients are estimated with zero uncertainty and abstracting from the uncertainty involved in simulating shocks at the individual level.

[19] Appendix F presents the evolution between 2020 and 2070 of the average partial healthcare expenditure associated to a specific set of diseases more prevalent among the elderly by gender.

Table 4: Public expenditure on long-term care between 2020 and 2070

Scenario		Projections							
		2020(*)	2025	2030	2040	2050	2060	2070	Change 2020-2070
Benchmark	Expenditure(a)	400.5	520.7	835.3	1528.9	1907.9	2336.4	2677.2	568.5%
	% of GDP(b)	0.7	0.8	1.1	1.8	2.0	2.3	2.5	1.8
	per capita(c)	0.6	0.8	1.2	2.1	2.5	3.0	3.4	431.5%
	per beneficiary(c)	41.7	41.3	47.1	62.3	66.9	69.8	76.2	83.0%
	Beneficiaries	9612	12615	17717	24555	28502	33495	35114	265.3%
Morbidity compression	Expenditure(a)	559.4	624.8	846.7	1471.9	1881.6	2181.0	2527.5	351.8%
	% of GDP(b)	1.0	0.9	1.1	1.7	2.0	2.1	2.4	1.4
	per capita(c)	0.9	0.9	1.2	2.0	2.4	2.8	3.2	259.2%
	per beneficiary(c)	55.6	48.8	49.6	62.5	69.9	71.5	76.9	38.2%
	Beneficiaries	10053	12801	17067	23560	26921	30495	32861	226.9%
Constant unit cost	Expenditure(d)	400.5	502.0	776.2	1320.3	1531.0	1742.2	1855.1	363.2%
	% of GDP(b)	0.7	0.7	1.0	1.5	1.6	1.7	1.7	1.1
	per capita(c)	0.6	0.8	1.1	1.8	2.0	2.2	2.4	268.3%
	per beneficiary(c)	41.7	39.8	43.8	53.8	53.7	52.0	52.8	26.8%
	Beneficiaries	9612	12615	17717	24555	28502	33495	35114	265.3%

(a) Million euros (b) thousand euros per capita (*) Results for 2020 do not account for Covid-19 pandemic effects.
Source: own calculations, BCL's long-term GDP projections.

In the **constant unit cost scenario**, total expenditure increases only by 363% between 2020 and 2070 (3.11% annual growth rate). Expenditure per beneficiary increases only by 27% but expenditure *per capita* increases by 268%. This indicates that population ageing, and the associated deterioration in health, has a limited effect on expenditure per beneficiary but an important effect on the number of beneficiaries. Finally, expenditure rises to 1.5% of GDP in 2040 and then grows slightly faster than GDP.

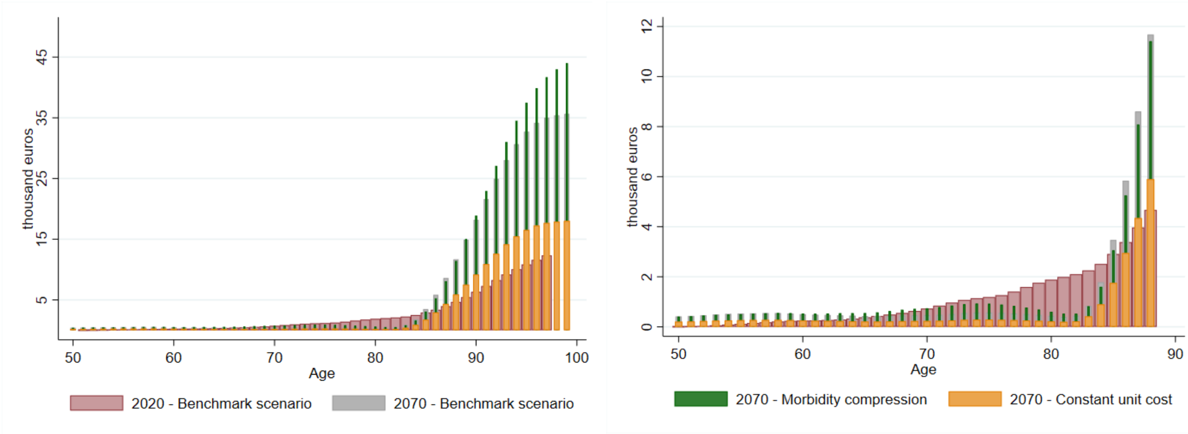
Focussing on the change between 2020 and 2070, in the constant unit cost scenario population ageing raises per capita expenditure by 1.8 thousand euros and per beneficiary expenditure by 11.1 thousand euros. Differences compared to the benchmark indicate that higher unit costs explain only 1 thousand euros of the increase in per capita expenditure and 23.4 thousand euros of the increase in per beneficiary expenditure. Differences compared to the morbidity compression scenario indicate that the latter would reduce per capita expenditure by 200 euros but increase per beneficiary expenditure by 700 euros.

Figure 3 depicts average expenditure on long-term care by age for those beneficiaries living at home, while Figure 4 focuses on those living in specialized institutions. The 2070 distribution is reported for each scenario, but the 2020 distribution is only reported for the benchmark, since it is very similar across scenarios. Panel (a) in Figure 3 covers beneficiaries from 50 to 100 years old and panel (b) focuses on beneficiaries younger than 89.

In panel (a), for both the benchmark and constant unit cost scenarios, average expenditure increases steadily with age. In panel (b), the unit cost scenario in 2070 (orange bars) indicates an increase in average expenditure from its 2020 level (brown bars) at the youngest and oldest age categories, but a decline in average expenditure for those between 60 and 86 years old. Even allowing for the increase in unit costs between 2020 and 2070, the benchmark results suggest that for these intermediate categories average expenditure declines from its 2020 level (brown bars) to its 2070 level (grey bars).

In the morbidity compression scenario (green bars), average expenditure generally increases with age, reflecting poor health concentrating among the elderly. However, the more detailed view in panel (b) reveals a local minimum in average expenditure at 82 years of age. Average expenditure under this scenario tends to be at least as high as its 2070 level in the benchmark (grey bars), except for those between 84 and 89 years old.

Figure 3: Long-term care, average expenditure by age (beneficiaries at home)

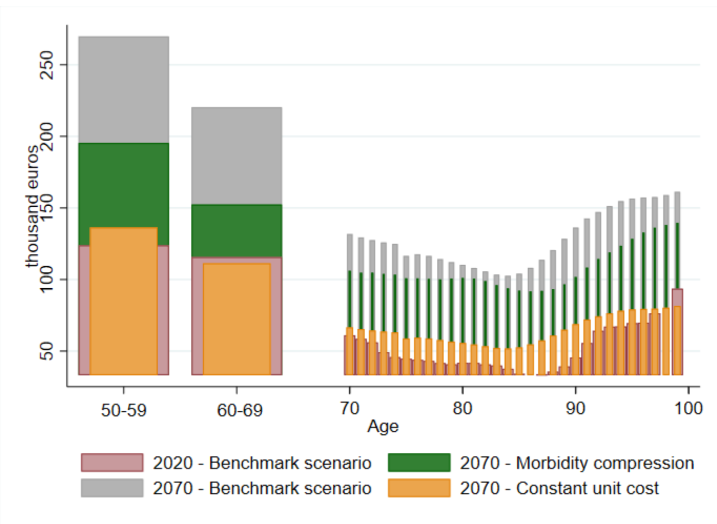


(a) All ages (b) Younger than 89

Source: Own calculations.

Figure 4 shows the distributions of average expenditure by age for those above 50 receiving aid at specialized institutions. Since there are few beneficiaries in specialized institutions that are younger than 70, Figure 4 only reports two broader categories for younger age groups.

Figure 4: Long-term care, average expenditure by age (beneficiaries at specialized institutions)



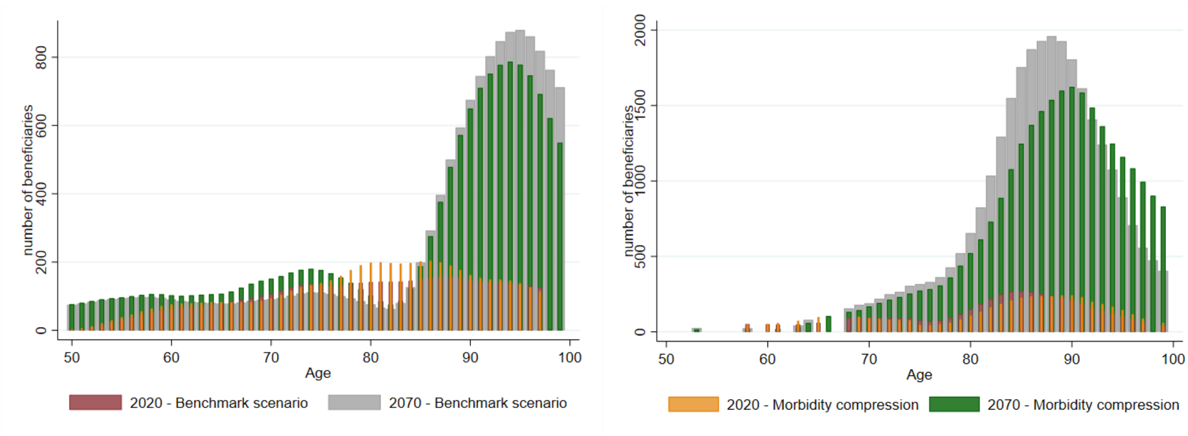
Source: Own calculations.

In Figure 4, if we compare 2020 (brown bars) to 2070 in the constant unit cost scenario (orange bars), average expenditure increases for all ages. In 2070, average expenditure in the benchmark even exceeds that in the morbidity compression scenario (green bars). This reflects the impact of evolving health on the number of beneficiaries of long-term care, which we analyse below.

Figure 5 focuses on the **number of beneficiaries** in the benchmark and morbidity compression scenarios. Panel (a) focusses on beneficiaries residing at home and panel (b) on those residing in specialized institutions. In panel (a), the number of beneficiaries in 2020 peaks in the ages 80-85 in both scenarios. However, there are slightly more beneficiaries in the morbidity compression scenario, reflecting poorer health of the elderly than in the benchmark. In panel (b), the 2020 distribution for the morbidity compression scenario (orange bars) is skewed to the right of the benchmark, with the number of beneficiaries peaking at ages 85-90.

On the one hand, returning to panel (a) to compare 2070 in the morbidity compression scenario (green bars) and in the benchmark (grey bars), the latter has more beneficiaries at ages 85-99 but fewer beneficiaries at ages 55-84. This is counterintuitive because morbidity compression should concentrate poor health among the oldest. However, poor health among the oldest requires at least as much expenditure as in the benchmark scenario, leading, as expected, to higher average expenditure in the older cohorts (Figure 3). On the other hand, panel (b) of Figure 5, which focused on specialized institutions, reports more beneficiaries above 91 in the morbidity compression scenario than in the benchmark. As a result, average expenditures are lower in the morbidity compression scenario than in the benchmark (Figure 4). In fact, the morbidity-compression scenario implies, first, more beneficiaries and lower average expenditure at higher ages and, second, lower average expenditure at younger ages.

Figure 5: Long-term care, number of beneficiaries by age



(a) Resident at home

(b) Resident in specialized institutions

Source: Own calculations.

Our analyses indicate that the morbidity compression scenario has a stronger effect on expenditure for beneficiaries in specialized institutions, who represent the largest share of long-term care. This helps to explain why this scenario features significantly lower aggregate expenditure after 2030 (Table 4).

Table 5 compares average expenditure for men and women using standard Student-t tests.[20] In 2020, differences are not statistically significant for those living in specialized institutions and only weakly significant for those living at home. In the latter group, average expenditure is higher for women. In 2070, average expenditure differs significantly between men and women. In particular, for those living at home average expenditure is higher for men and for those living in specialized institutions average expenditure is higher for women.

Table 5: Average long-term care expenditure, comparisons by gender

Year	Aid received at	Group	Obs.	Mean	Std.Er.	[95% Conf. Int.]		Mean comparison test Ho: Diff.=0	(p-value)
2020	Home	Women	2936	29902	240.4	29431	30373	t = 1.771	df= 4899
		Men	1965	29273	243.9	28795	29751	Ha: Diff.<0	(0.9617)
		Combined	4901	29650	174.1	29308	29991	Ha: Diff.!=0	(0.077)
		Diff.		629.1	355.2	-67.24	1325	Ha: Diff.>0	(0.038)
	Spec. Inst.	Women	3255	53826	646.9	52558	55095	t = 0.809	df= 4778
		Men	1525	52868	1041	50826	54911	Ha: Diff.<0	(0.791)
		Combined	4780	53521	551.8	52439	54602	Ha: Diff.!=0	(0.418)
		Diff.		958.02	1183	-1.363	3278	Ha: Diff.>0	(0.209)
2070	Home	Women	7648	27951	109.3	27736	28165	t = -26.413	df= 12816
		Men	5170	32861	158.1	32551	33171	Ha: Diff.<0	(0.000)
		Combined	12818	29931	93.6	29748	30115	Ha: Diff.!=0	(0.000)
		Diff.		-4910	185.9	-5275	-4546	Ha: Diff.>0	(1.000)
	Spec. Inst.	Women	20042	64978	211.8	64563	65393	t = 15.703	df= 28288
		Men	8248	59164	261.1	58652	59675	Ha: Diff.<0	(1.000)
		Combined	28290	63283	169.0	62951	63614	Ha: Diff.!=0	(0.000)
		Diff.		5814	370.3	5088	6540	Ha: Diff.>0	(0.000)

Source: Own calculations.

Unlike the pairwise comparisons in Table 5, the regressions reported in Table 6 can account for the simultaneous effects of several variables. In particular, they illustrate how the gender gap in average expenditure on long-term care varies with age (see Table 6, rows (2) *Gender,* (4) *Gender x Institution*, (6) *Age x Gender and* (8) *Age x Gender x Institution*). In 2020 (column 1), estimated marginal effects indicate a significant gender gap. First, we consider beneficiaries who live at home. Among those younger than 69, average expenditure is higher for men. Among those older than 73, expenditure is higher for women. Between 69 and 72, the difference between men and women is not statistically significant. Now we turn to those living in specialized institutions. Among those younger than 85, average expenditure is higher for men. Among those older than 85, average expenditure is higher for women. In 2070 (column 2), among those living at home, average expenditure is systematically higher for men regardless of age. Now we turn to those living in specialized institutions. Among those younger than 84, average expenditure is higher for men. Among those older than 84, average expenditure is higher for women.

[20] These treat simulated data as if it were actually observed, implicitly assuming coefficients are estimated with zero uncertainty and abstracting from the uncertainty involved in simulating shocks at the individual level.

Table 6: Linear regression of long-term care expenditure in 2020 and 2070 (benchmark scenario)

Variables	**(1)** **2020**	**(2)** **2070**
(1) Age	-1,980***	-683.1***
	(93.49)	(36.11)
(2) Gender	-31,320***	52,970***
	(2,964)	(2,732)
(3) Institution	-4,743	-109,644***
	(6,817)	(3,454)
(4) Gender x Institution	210,287***	126,104***
	(11,885)	(6,780)
(5) Health index	-182,212***	-217,609***
	(16,464)	(12,696)
(6) Age x Gender	442.9***	-541.3***
	(38.81)	(29.83)
(7) Age x Institution	371.6***	1,687***
	(81.56)	(39.53)
(8) Age x Gender x Institution	-2,530***	-1,587***
	(142.3)	(76.85)
(9) Age x Health index	3,717***	2,683***
	(223.0)	(142.7)
Constant	140,679***	80,056***
	(6,701)	(3,127)
Observations	9,681	41,108
R-squared	0.417	0.380

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Source: Own calculations.

6. Conclusion

In this paper, we adapt the standard theoretical model of optimal intertemporal consumption to simulate long-term trends of public expenditure on healthcare and long-term care in Luxembourg. In particular, we analyse the impact of population growth and demographic ageing on individual health and analyse the effects on public expenditure.

Model equations are estimated and calibrated using data from the SHARE survey, as well as aggregate data from various public administrations in Luxembourg. These equations are then combined with EUROSTAT population projections in a dynamic simulation exercise. Results allow us to estimate the contribution of specific diseases to public expenditure on healthcare and long-term care. To illustrate, we design scenarios that show how long-term trends in health-related public expenditure depend on demography, cost of producing health-related services, and the distribution of health across age cohorts. In addition, we simulate the evolution of gender gap in public expenditure on health-related services.

According to our benchmark scenario, public expenditure on healthcare will rise from 5.8% of GDP in 2020 to 7% in 2070. In per capita terms, population ageing would explain more than a quarter of the increase, with rising costs of production accounting for the rest. Public expenditure on long-term care should rise from 0.7% of GDP in 2020 to 2.5% in 2070. Rising costs of production would explain more than a third of the increase in per capita terms and two thirds of the increase in per beneficiary terms.

Our projections are in line with the analysis by the European Commission, which warns that among EU countries, Luxembourg will face the sharpest increase in ageing-related spending (European Commission, 2020). Although Luxembourg's Social Security system is currently in a comfortable financial situation, the projected increase in spending endangers its sustainability. While pensions would be the main driver of the increase in spending, enhancing the efficiency of healthcare and long-term care could contribute to limit the impact on public finances.

Our simulations cover a very long horizon, so the traditional caveats apply. We assume constant preferences and moderate productivity growth in order to focus on population ageing and its likely impact on average health status. However, over the next fifty years, supply and demand for healthcare and long-term care services could change substantially. For instance, medical innovations could provide cheaper and more effective substitutes for current treatments, as well as new (potentially) expensive treatments, income growth and changes in the income distribution could affect the demand for healthcare, new diseases (e.g. Covid-19) may alter the age-related path of individuals' health status and, of course, demographic projections are also subject to uncertainty.

Subject to these caveats, our model of individual behaviour can still contribute to *ex-ante* evaluation of health-related policies. Future research could extend both our empirical and theoretical results. On the empirical side, we plan to apply the model to analyse specific conditions associated with ageing, such as dementia, which affects more than 28% of long-term care beneficiaries above the age of 80. We also plan to study the effect on public expenditure of technological innovations, prevention policies and behavioural/lifestyle changes among younger generations in Luxembourg. In a further step, we plan to estimate and simulate individual consumption and saving paths to assess welfare effects of alternative policies aimed at curbing public expenditure on health-related services. On the theoretical side, we plan to extend the model with a working time decision and a more detailed characterisation of individual preferences.

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Appendix A: The theoretical model

The theoretical model builds on Deaton (1991) and De Nardi et al. (2006). We modify their model to focus on how individual characteristics including health-related behaviour can affect individual health status, as well as aggregate health-related expenditure and the government budget balance.

Individuals maximize their expected lifetime utility by choosing a path of current and future consumption at ages a ($a = 50, \ldots, a_r, \ldots, A_g$), where a_r is the retirement age, A_g is the last year of life and g indicates gender (male or female). This decision depends on several individual characteristics, of which some are exogenous, such as gender, childhood circumstances and health-related behaviour, and others are endogenous, such as health status and working status. Health-related behaviour such as physical activity may reduce working time and therefore income and consumption, but also improves health status.

In each period t, the individual's utility depends on current consumption c and on health status m. Within-period utility is defined as follows:

$$U = \begin{cases} \nu c_{a,g,t} - \delta_0(\delta_1 + m_{a,g,t}) c_{a,g,t}^2, & \text{for } a = 50, \ldots, a_r, \ldots, A_g - 1 \\ \nu c_{A_g,g,t} - \delta_0(\delta_1 + m_{a,g,t}) c_{A_g,g,t}^2 - \phi b_{A_g,g}, & \text{for } a = A_g \end{cases} \quad \text{(A.1)}$$

where, the parameters ν, δ_0 and δ_1 satisfy $\nu > 0$ and $\delta_0(\delta_1 + 1) \leq \frac{\nu}{2}$ so that health status m also affects the marginal utility of consumption. Age $a = A_g$ represents life end, when the utility function includes a "warm glow" term (De Nardi, 2004) that values gross bequests (before taxes) by reducing the utility of consumption.

Individual health status can take any value between 0 (healthy) and 1 (completely unhealthy). Health status m is a weighted average of health conditions d (including depression, problems with memory, eyesight, hearing, etc.). Each health condition depends on a vector e_d of diseases, limitations on daily activities, and/or symptoms from set m^d: $f^d(e_d)$. For simplicity, we use "disease" to refer to all components of e_d:

$$m_{a,g} = \sum_{\forall d} \gamma_d m_{a,g}^d, \quad \text{with } m_{a,g}^d \in [0,1], \quad \text{(A.2)}$$

where, γ_d is the weight associated with health condition d. Our modeling of health status extends the literature, which generally only considers a few health states (e.g. good health, bad health). This allows us to analyze the long-term effects of specific diseases.

The individual faces three types of risk: working status risk, health status risk and survival risk. First, regarding working status, we assume that the active individuals (i.e., $a < a_r$) become unemployed, disabled or early-retired with probabilities that depend on a vector of exogenous variables (X, which includes gender g) and a vector of exogenous variables (Z, which includes health status $m_{a,g}$). However, we assume that all individuals reaching age a_r retire with certainty. In addition, individuals who switch to early retirement cannot switch back. For simplicity, we do not consider shocks at the household level but only focus on risks affecting individuals.

To determine the working status of individuals in active age, we adopt an additive random utility framework[21] based on the following system of latent variables:

[21] See section 15.5 in Cameron and Trivedi (2005). For applications of this modelling approach to labour economics see Dagsvik et al.'s (2014) survey. For an extension see Dagsvik and Jia (2016).

$$WS_{a,g}^{k} = X_{a,g}\beta_X^k + Z_{a,g}\beta_Z^k + \zeta^k + u^k, \qquad k = E, UN, ER, D \tag{A.3}$$

with E for employed, UN for unemployed, ER for early-retired and D for disable and where, u^k is joint normally distributed random variable representing the source of risk and ζ^k a structural parameters with $k \in \{E, UN, ER, D\}$.

The probability that an individual of age a and gender g chooses working status $S_{a,g}^{j}$, with j and k belonging to $\{E, UN, ER, D\}$, is:

$$Pr\left(S_{a,g}^{j} = 1\right) = Pr\left(u_{a,g}^{k} - u_{a,g}^{j} \leq WS_{a,g}^{j} - WS_{a,g}^{k}\right), \quad \forall k \neq j \tag{A.4}$$
$$= Pr\left(\tilde{u}_{a,g}^{k,j} \leq -\widetilde{WS}_{a,g}^{k,j}\right), \ \ \forall k \neq j$$

where the tilde and the second superscript indicate differencing with respect to reference alternative j.

For example, using the last equality in (A.4), the probability of early retirement is:

$$Pr\left(S_{a,g}^{ER} = 1\right) = \ Pr\left(\tilde{u}_{a,g}^{k,ER} \leq -\widetilde{WS}_{a,g}^{k,ER}\right) \qquad \forall k \neq ER \tag{A.5}$$
$$= Pr\left(\tilde{u}_{a,g}^{E,ER} \leq -\widetilde{WS}_{a,g}^{E,ER}, \tilde{u}_{a,g}^{UN,ER} \leq -\widetilde{WS}_{a,g}^{UN,ER}, \tilde{u}_{a,g}^{D,ER} \leq -\widetilde{WS}_{a,g}^{E,ER}\right)$$
$$= \int_{-\infty}^{-\widetilde{WS}_{a,g}^{E,ER}} \int_{-\infty}^{-\widetilde{WS}_{a,g}^{UN,ER}} \int_{-\infty}^{-\widetilde{WS}_{a,g}^{D,ER}} f\left(\tilde{u}_{a,g}^{D,ER}, \tilde{u}_{a,g}^{UN,ER}, \tilde{u}_{a,g}^{HM,ER}, \tilde{u}_{a,g}^{E,ER}\right) d\tilde{u}_{a,g}^{D,ER}\, d\tilde{u}_{a,g}^{UN,ER}\, d\tilde{u}_{a,g}^{E,ER},$$

which is a four-variate integral without analytical solution.

Note that the probability of an individual of age a and gender g to be retired is:

$$Pr\left(S_{a,g}^{R} = 1\right) = \begin{cases} 1 & \text{if } a \geq a_r \\ 0 & \text{otherwise} \end{cases}. \tag{A.6}$$

Furthermore, we assume that the individual's contribution to household non-asset income[22] is a deterministic function of his/her working status (i.e., employed, unemployed, retired, and disabled), gender and age. Thus, non-asset income of retired individual of gender g is $R_{rt,g}$. Otherwise, if $a < a_r$, non-asset income is:

$$y_{a,g} = \begin{cases} Y_{a,g} - w_{a,g}hb_g & \text{(employed)} \\ Y_{a,g}^{UN} & \text{(unemployed)} \\ R_{a,g}^{ER} & \text{(early retired)}, \\ R_{a,g}^{R} & \text{(retired)} \\ R_{a}^{D} & \text{(disabled)} \end{cases} \tag{A.7}$$

with $Y_{a,g}^{UN} < Y_{a,g} - w_{a,g}hb_g$ and $R_a^D \leq R_{a,g}^{ER} \leq R_{a,g}^{R} < Y_{a,g} - w_{a,g}hb_{a,g}$.

Equation (A.7) assumes that time spent on health-related behaviour hb_g reduces the income of employed individuals. To avoid perverse incentives we assume that unemployment benefits are always lower than employed income even after accounting for hb_g. To limit the number of state variables, we assume that health-related behaviour does not evolve over time.

[22] Henceforth, "individual's income" refers to the individual's contribution to household non-asset income.

Second, the individual faces health status uncertainty. Let $I_{a,g}^{i}=1$ indicates if disease i in Φ affects an individual of age a and gender g. On the contrary, $I_{a,g}^{i}=0$ indicates that disease i in Φ does not affect such an individual. The probability that $I_{a,g}^{i}=1$ depends on his/her health-related behaviour and concomitant diseases (vector O), in addition to variables in vectors $X$and Z. Thus,

$$Pr\left(I_{a,g}^{i}=1 \,\middle|\, X_{a,g}, Z_{a,g}, hb_{a,g}, O_{a,g}\right) = \tag{A.8}$$

$$= F_i\left(-u_{a,g}^{i} < X_{a,g}\beta_X^i + Z_{a,g}\beta_Z^i + O_{a,g}\beta_O^i + hb_{a,g}\gamma^i - \zeta^i\right), \quad \forall i \in \Phi$$

where we assume $u_{a,g}^{i}$ is normally distributed random variable representing the source of risk with cumulative distribution function F_i and ζ^i a structural parameter.

Finally, every individual faces survival risk. We note by $sp_{a,g,m}$ the probability that an individual of age a and gender g is alive at age $a+1$, conditional on being alive at age a with health status m. The probability function satisfies $\partial sp_{a,g,m}/\partial m > 0$. Since health status depends on health-related behaviour and other variables (see Eq. (A.8)), these factors indirectly affect the individual's survival probability.

Unlike De Nardi et al. (2006), current health-related expenditure is not subject to risk once individual health status is known. Our model disentangles the roles of production cost of health services and of health status risk and in health-related expenditure. For a given individual, the sum of healthcare expenditure and long-term care expenditure $hc_{a,g,m}(\pi_t)$ is a deterministic function of age, gender, health status and π_t, the share of expenditure covered by the government. This function makes it possible to account for changes in health-related public transfers (e.g. partial/full coverage of costs associated with specific diseases).

At the beginning of each period, realizations of the independent and identically distributed stochastic shocks u^k and u^i determine the working status and health status of every individual. Therefore, expenditure on healthcare and long-term care is known before individuals decide how much to consume and save. Finally, based on the survival probabilities $sp_{a,g,m}$, those individuals who continue into the next period are randomly selected.

Individuals are endowed with a stock of net assets W that evolves as follows:

$$W_{a,g,t+1} = W_{a,g,t} + ny\left(r_t W_{a,g,t} + y_{a,g}, \tau_t^y\right) - ds_{g,t} + tr_{a,g,t} - hc_{a,g,m}(\pi_t) - c_{a,g,t} + \left(1-\tau_t^b\right)b_{a,g}, \tag{A.9}$$

where, index t indicates the year, $ny\left(r_t W_{a,g,t} + y_{a,g}, \tau_t^y\right)$ denotes after-tax income (r_t being the rate of return and τ_t^y describing the income tax structure), $ds_{g,t}$ debt service, $tr_{a,g}$ public transfers and the last term, $(1-\tau_t^b)b_{a,g}$, denotes net bequests (i.e., after inheritance taxes τ_t^b) at age a. To account for potential changes to taxes, consumption is indexed by t. To limit the number of control variables, we assume that individuals can only inherit once in their lifetime and can only bequeath at age T_g (i.e., $b_{a,g} \geq 0$ if $a < A_g$ and $b_{a,g} < 0$ if $a = A_g$). To value bequests, the utility function in (A.1) includes a "warm glow" term at age A_g (see De Nardi, 2004).

Following De Nardi et al. (2006), we use the assumption in Hubbard et al. (1994) that public transfers ensure a consumption floor $c_{min,t}$:

$$tr_{a,g} = max\left\{0, c_{min,t} + hc_{a,g,m}(\pi_t) + ds_{g,t} - \left[W_{a,g,t} + \left(1-\tau_t^b\right)b_{a,g} + ny\left(r_t W_{a,g,t} + y_{a,g}, \tau_t^y\right)\right]\right\}. \tag{A.10}$$

In Eq. (A.10), public transfers ensure a minimum consumption level but cannot be used to finance bequests.

For simplicity, solvency risks are not modelled (i.e. net assets are always positive). To enforce the minimum consumption level and ensure that assets are always positive, we impose,

$$c_{a,g,t} \geq c_{min,t}, \forall t, \tag{A.11}$$

$$W_{a,g,t} \geq 0, \ \forall g, t. \tag{A.12}$$

We solve the individual's value function by backward induction with φ being the discount factor:

$$V_{a,g,t}\left(W_{a,g,t}, DEM_{a,g}, SEC_{a,g}, m_{a,g}\right) = \max_{c_{a,g,t}}\left\{U\left(c_{a,g,t}, m_{a,g}\right) + \varphi E_t\left[V_{a,g,t+1}\left(W_{a,g,t+1}, DEM_{a+1,g}, SEC_{a+1,g}, m_{a+1,g}\right)\right]\right\}, \ a = 50, \dots 100 \text{ and } t = 2020, \dots 2070$$

subject to Eq. (A.9) to (A.12).

Solution and comparative static results

Below, equation (A.13) provides the analytical expression for the consumption path for each individual not receiving social transfers. Henceforth, the interior solution. The corner solution corresponds to those individuals that do not have sufficient resources to consume $c^*_{a,g,t}$ and therefore, receive social transfers to consume c_{min}.

The interior solution is obtained by backward induction with transversality conditions $W_{g,A_g+1} = 0$ and $V_{A_g+1}\left(W_{g,A_g+1}\right) = -\frac{\phi b_{A_g}}{\varphi}$. For simplicity, we acknowledge that consumption depends on taxation τ^c_t, but we do not model it explicitly. Moreover, we assume that the net income function equals $ny\left(r_t W_{a,g,t} + y_{a,g}, \tau^y_t\right) = \left(1 - \tau^y_t\right)\left(r_t W_{a,g,t} + y_{a,g}\right)$.

The interior solution for the consumption of an individual of gender g at age a in period t is:

$$c^*_{a,g,t}(\tau^c_t) = \frac{1}{2\delta m_{a,g}}\left\{\nu - \phi\left\{1 - sp_{a,g}\left[1 - \varphi\left[1 + r_{t+1}\left(1 - \tau^y_{t+1}\right)\right]\left[1 - sp_{a+1} + \sum_{j=a+2}^{A_g-1} \varphi^{j-a-1}\left[1 + r_{j-a+t}\left(1 - \tau^y_{j-a+t}\right)\right]\left(1 + sp_{j-1}\right)\left(1 - sp_j\right) + \prod_{l=a+2}^{A_g} \varphi^{l-a-1}\left[1 + r_{l-a+t}\left(1 - \tau^y_{l-a+t}\right)\right]\left(1 + sp_{l-1}\right)\right]\right]\right\}\right\}. \tag{A.13}$$

The stock of assets held by an individual of gender g at age a in period t is obtained by replacing Eq. (A.13) in Eq. (A.9):

$$W_{a,g,t} = W_{a,g,t-1} + ny\left(r_{t-1}W_{a,g,t-1} + y_{a-1,g}, \tau^y_{t-1}\right) - ds_{g,t-1} + tr_{a-1,g,t-1} - hc_{a-1,g,m}(\pi_{t-1}) - c^*_{a-1,g,t-1}(\tau^c_{t-1}) + \left(1 - \tau^b_{t-1}\right)b_{a-1,g}. \tag{A.14}$$

Beyond the current period t, the evolution of the stock of assets also depends on the expected evolution of health and income. For an individual of gender g at age a in period l:

$$W_{a,g,l} = W_{a,g,l-1} + ny\left(r_{l-1}W_{a,g,l-1} + E\left(y_{a-1,g}\right), \tau^y_{l-1}\right) - ds_{g,l-1} + tr_{a-1,g,l-1} - E\left(hc_{a-1,g,m}(\pi_{l-1})\right) - c^*_{a-1,g,l-1}(\tau^c_{l-1}) + \left(1 - \tau^b_{l-1}\right)b_{a-1,g}, \quad t < l \leq A_g. \tag{A.15}$$

Risks are modelled as continuous random variables. The conditional expectations operators for non-asset income of an active individual (i.e., not retired or early-retired) are derived from Eq. (A.5). The expectations operator for health expenditures are derived from Eq. (A.8).

In each period t, a deterioration in health status (i.e. an increase in $m_{a,g}$) reduces individual consumption:

$$\frac{\partial c^*_{a,g,t}(\tau^c_t)}{\partial m_{a,g}} = -\frac{\phi\Psi}{2\delta m_{a,g}} - \frac{c^*_{a,g,t}(\tau^c_t)}{m_{a,g}} < 0,$$

where,

$$\Psi = -\frac{\partial sp^t_{a,g}}{\partial m_{a,g}}\left[1-\varphi\left[1+r_{t+1}\left(1-\tau^y_{t+1}\right)\right]\left[1-sp^{t+1}_{a+1}+\sum_{j=a+2}^{A_g-1}\varphi^{j-a-1}\left[1+r_{j-a+t}\left(1-\tau^y_{j-a+t}\right)\right]\left(1+sp^{t+j-1-a}_{j-1,g}\right)\left(1-sp^{t+j-a}_{j,g}\right)+\prod_{l=a+2}^{A_g}\varphi^{l-a-1}\left[1+r_{l-a+t}\left(1-\tau^y_{l-a+t}\right)\right]\left(1+sp^{t+l-1-a}_{l-1,g}\right)\right]\right] - sp^t_{a,g}\left[-\varphi\left[1+r_{t+1}\left(1-\tau^y_{t+1}\right)\right]\left[-\frac{\partial sp^{t+1}_{a+1,g}}{\partial m_{a+1,g}}\frac{\partial m_{a+1,g}}{\partial m_{a,g}}+\sum_{j=a+2}^{A_g-1}\varphi^{j-a-1}\left[1+r_{j-a+t}\left(1-\tau^y_{j-a+t}\right)\right]\left[\left(1-sp^{t+j-a}_{j,g}\right)\frac{\partial sp^{t+j-1-a}_{j-1,g}}{\partial m_{j-1,g}}\frac{\partial m_{j-1,g}}{\partial m_{a,g}}-\left(1+sp^{t+j-1-a}_{j-1,g}\right)\frac{\partial sp^{t+j-a}_{j,g}}{\partial m_{j,g}}\frac{\partial m_{j,g}}{\partial m_{a,g}}\right]+\sum_{l=a+2}^{A_g}\varphi^{l-a-1}\left[1+r_{l-a+t}\left(1-\tau^y_{l-a+t}\right)\right]\frac{\partial sp^{t+l-1-a}_{l-1,g}}{\partial m_{l-1,g}}\frac{\partial m_{l-1,g}}{\partial m_{a,g}}\prod_{\forall k\neq l}^{A_g}\varphi^{k-a-1}\left[1+r_{t-a+k}\left(1-\tau^y_{t-a+k}\right)\right]\left(1+sp^{t+k-1-a}_{k-1,g}\right)\right]\right] > 0.$$

A multi-period analysis would have to allow for the effect on the expectations operator, which would reinforce the decline in current consumption.

The government budget balance

The evolution of the health status of the population affects public finances through changes in tax revenue. Additionally, in an economy with a public healthcare insurance (i.e., $\pi_t > 0$), there is an effect through health-related expenditure also. In each period t, the public finance balance is:

$$B_t = P_t + \sum_{\forall a,\forall g}\left[R\left(r_t W_{a,g}+y_{a,g},\tau^y_t\right)+\tau^b_t b_{a,g}+T\left(c_{a,g,t}(\tau^c_t),\tau^c_t\right)\right]-\left(G_t+\sum_{\forall a,\forall g}tr_{a,g}+\sum_{\forall a,\forall g}\pi_t hc_{a,g,m}(\pi_t)+\sum_{\forall a\geq a_r,\forall g}R_{rt,g}+\sum_{\forall a,\forall g}\bar{R}_{rt,g}\right). \quad \text{(A.16)}$$

On the right hand side, the first two terms represent revenue from taxes on firms P_t and on individual asset and non-asset income ($R(\cdot)$ with tax scheme τ^y_t), bequests (with tax rate τ^b_t) and consumption ($T(\cdot)$ with tax scheme τ^c_t). Then, public expenditure consists of general purpose expenditure G_t, social transfers $\left(\sum_{\forall a,g} tr_{a,g}\right)$, public health insurance benefits $\left(\sum_{\forall a,g} hc_{a,g,m}(\pi_t)\right)$, and public retirement transfers (the last two sums). The closer to one is the factor π_t, the more generous is the public health insurance. In this simplified framework, tax revenue from firms and general purpose public expenditure may change across periods but are not directly affected by demography. On the other hand, demographic evolution affects tax revenue from individual income and consumption, and from inheritance taxation.

In each period t, a worsening of health status of each individual in the population (i.e. an increase in $m_{a,g}$) deteriorates the government budget balance because of higher transfers and lower tax revenue from consumption and inheritance:

$$\frac{\partial B_t}{\partial m} = \sum_{\forall a,g}\left(\frac{\partial R_{a,g,t}}{\partial m_{a,g}}+\tau^b\frac{\partial b_{a,g}}{\partial m_{a,g}}+\frac{\partial T\left(c^*_{a,g,t}(\tau^c_t),\tau^c_t\right)}{\partial c^*_{a,g,t}\left(\tau^c_t\right)}\frac{\partial c^*_{a,g,t}(\tau^c_t)}{\partial m_{a,g}}\right)-\sum_{\forall a,g}\left(\frac{\partial tr_{a,g}}{\partial m_{a,g}}+\pi_t\frac{\partial hc_{a,g,m}(\pi_t)}{\partial m_{a,g}}\right) < 0.$$

A multi-period analysis would have to allow for the effect on the expectations operator, which would imply lower tax revenue from income.

Changes in the distribution of health status across the population will have more complex effects on the government budget balance. For simplicity, we consider two generations, with generation 1 transferring health to generation 2. Young individuals are from generation 1 (i.e. $a_1 < a_2$), which includes N_1 individuals, and old individuals are from generation 2, which includes N_2 individuals. The health status of the population does not change after the health transfer: $m = \alpha_1 m_{a_1} + \alpha_2 m_{a_2} = \alpha_1 m'_{a_1} + \alpha_2 m'_{a_2}$, where $\alpha_1 = \frac{N_1}{N_1+N_2}$ and $\alpha_2 = \frac{N_2}{N_1+N_2}$. Before the health transfer, the young have better health than the old generation: $m_{a_1} < m_{a_2}$, and therefore expend less on healthcare $hc_{a_1} < hc_{a_2}$. After the transfer, health improves for the old generation ($m'_{a_2} < m_{a_2}$) and deteriorates for the young ($m_{a_1} < m'_{a_1}$) and healthcare expenditure adapt accordingly. In period t, The effect on public healthcare expenditure depends on the relative size of each generation and on the relative changes in healthcare expenditure: $\pi_t\left[\left(hc'_{a_1} - hc_{a_1}\right)N_1 - \left(hc_{a_2} - hc'_{a_2}\right)N_2\right]$. In a multi-period analysis, the effect on tax revenue should be factored in.

Appendix B: Data used to calibrate healthcare and long-term care expenditure

To calibrate the individual's partial healthcare expenditure in Luxembourg, information is taken from:

- The Blue book – Version coordinated on March 30, 2020 of the nomenclature of doctors and dentists (https://cns.public.lu/dam-assets/legislations/texte-coordonne/livre-bleu/Livre-bleu-01-10-2021.pdf).
- The Green book – Version coordinated on March 19, 2020 of the nomenclature of nurses, physiotherapists, psychomotor therapists, midwives, speech therapists, medical analysis and clinical biology laboratories, palliative care providers, and dieticians (https://cns.public.lu/dam-assets/legislations/texte-coordonne/livre-bleu/Livre-bleu-01-10-2021.pdf).
- Positive list (*Liste positive*) of drugs valid as of August 1, 2020. This list is based on data within the competence of the Pharmacy and Medicines Division and the Ministry of Social Security. Specifically, the list gives the drugs price as well as the repayment rate, which is important in our model to account for public expenditure (https://cns.public.lu/fr/legislations/textes-coordonnes/liste-positive.html).
- File B3 valid on August 1, 2019, contains the price of the hearing correction device (https://cns.public.lu/dam-assets/legislations/statuts/b3/202105-b3.pdf).

To calibrate the algorithm for selecting individuals necessitating long-term care, we use information from different sources:

- Annual General Report of the Social Security, 2019 (https://gouvernement.lu/dam-assets/documents/actualites/2020/01-janvier/rg-sec-soc-2019.pdf).
- Administration of Evaluation and Control of the Dependency Insurance (https://aec.gouvernement.lu/fr/l-assurance-dependance.html).
- The Law of 29 August 2017 amending the Social Security Code (http://legilux.public.lu/eli/etat/leg/loi/2017/08/29/a778/jo).
- Grand-Ducal Regulation of 18 September 2018 Amending the Grand-Ducal Regulation of 18 December 1998 laying down the procedures for the determination of dependence.
- The socio-parameters from the General Social Security Inspectorate (https://gouvernement.lu/dam-assets/documents/actualites/2020/05-mai/Paramètres-sociaux-200520.pdf).

Appendix C: Construction of health conditions used in the health status indicator

Table C.1. Depression

Depression scale Euro-d*	Assigned value
Not depressed (0 dimension)	0
Between 1 and 11 dimensions	$1 - (12 - X_i)/12$
Completely depressed (12 dimensions)	1

* Depression, pessimism, suicidal thoughts, guilt, sleep, interest, irritability, appetite, tiredness, concentration, enjoyment, tearfulness.

Table C.2. Orientation

Orientation		Assigned value
Four questions have been asked regarding date, day of the week, month, and year	Knows all	0
	Knows 3 of 4	0.25
	Knows 2 of 4	0.50
	Knows 1 of 4	0.75
	None of them	1

Table C.3. Memory

Capacity to memorize words		Assigned value
How many words do you recall?*	More than 15 words	0
	More than 1 and less than 16	$(16 - X_i)/14$
	Only 1	1

* This number is the sum of the first trial and the delayed trial.

Table C.4. Permanent conditions

Permanent		Assigned value
Do you have any permanent health problems, illness, disability or infirmity?*	No	0
	One	0.75
	More than one	1

* Hypertension, high cholesterol, diabetes, pneumonia, Parkinson, Alzheimer, anxiety, rheumatism, arthrosis, kidney.

Table C.5. Non-permanent conditions

Non-permanent		Assigned value
Do you have any non-permanent health problems, illness, disability or infirmity?*	No	0
	One	0.75
	More than one	1

* Heart attack, stroke, cancer, ulcer, cataract, femur break, fractures.

Table C.6. Limitation on activities 1

Health and daily activities		Assigned value
Because of a health problem,	No	0
do you have difficulty doing any	Somewhat	$1 - (6 - X_i)/6$
of the following daily activities?*	Yes	1

* Dressing, bathing or showering, eating, cutting food, walking across a room, getting in or out of bed.

Table C.7. Limitation on activities 2

Health and general activities		Assigned value
Because of a health problem,	No	0
do you have difficulty doing any	Somewhat	$1 - (4 - X_i)/4$
of the following activities?*	Yes	1

* Walking 100 meters, walking across a room, climbing several flights of stairs, climbing one flight of stair.

Table C.8. Eyesight

Farsighted and near-sighted*	Assigned value
Both are E or VG	0
Any other combination	$1 - (6 - X_i)/4$
Both are P	1

*E: excellent, VG: very good, G: good, F: fair, P: poor.

Table C.9. Hearing

Hearing		Assigned value
Is your hearing*	Excellent or Very good	0
	Good	0.20
	Fair	0.50
	Poor	1

*With or without a hearing aid.

Appendix D: Healthcare insurance expenditure

Partial healthcare expenditure

To compute partial healthcare expenditure, we focus on a subset of twenty-one diseases to which we associate expenditure based on the in kind benefits proposed by the CNS. The subset of diseases includes: depression, memory, heart attacks, hypertension, high cholesterol, stroke, diabetes, pneumonia, cancer, ulcer, Parkinson, cataract, femur brake, other fractures, Alzheimer, other type of dementia, eyesight, hearing, kidney problem, rheumatism and arthrosis. For each of these diseases, we build an *expenditure matrix*, which, depending on the type of disease, can include expenditure associated with visits to specialist physicians, laboratory analysis, nights at hospital, medical devices, drug treatments, and technical acts performed by doctors or others specialists.

To calibrate each element of the expenditure matrices, we use data from the Ministry of Social Security.[23] In particular, we use the annual average number of visits to specialist physicians and the annual average of nights at hospital, both by age and gender.[24] To compute expenditure related to these benefits in kind, we apply the 2020 official lump-sum rate for a specialist physician and the 2020 official rates per night at hospital. In this last case, we consider the day (working day or weekend) and hour (day or night) of admission, the length of the stay, and the service through which the individuals are admitted (i.e., emergency, cardiology, other) depending on the disease. Our estimate of hospital expenditure only covers the cost of the stay, as no information is available on treatments, analyses, and other care provided.

In addition, for some diseases, we calculate the annual expenditure of generic medical treatments following the recommendations of the Scientific Council on health in Luxembourg or in neighbouring countries, if the information was not available in the country (see Appendix F).[25] These medical treatments may include the use of medical devices, drugs, laboratory analysis and/or technical acts performed by doctors (surgeries, punctures, medical imaging, etc.) or others specialists (psychomotor rehabilitators, physiotherapists, speech therapists, etc.). For some diseases, the treatments vary with the numbers of years since diagnosis (e.g. Parkinson) and/or potential concomitant diseases. To compute the expenditure related to these treatments we use 2020's official rates. In the particular case of drug treatments, we first identified the standardly recommended annual consumption by a patient by age and then, if alternative drugs were available for treating the same disease, we calculated the average cost.

Finally, to calculate a partial healthcare expenditure, we associate to each disease the individual may have its respective expenditure matrix. It is important to notice, however, that in the specific case of nights at hospital, this element of the matrices is assigned only to some randomly chosen individuals having the specific disease. For instance, not all individuals suffering from depression are hospitalized.

Mapping partial healthcare expenditure to total healthcare public expenditure

To calculate total healthcare expenditure for the entire insured population in Luxembourg (resident and non-resident) based on the partial healthcare expenditure, we proceed in two steps.

First, using data provided by the General Social Security Inspectorate (IGSS) for 2012, we estimate the following mapping function:

[23] See Appendix B for more information on the different data sources from the Ministry of Social Security.
[24] This information was provided by the CNS for years 2013 to 2016.
[25] Information available in http://conseil-scientifique.public.lu/fr.html

$$\bar{e} - e = +\beta_1^e m + \beta_2^e SEX + \beta_3^e Edu + \beta_4^e AGE + \beta_5^e AGE^2 + \beta_6^e AGE^3 + u^e. \quad \text{(D.1)}$$

The dependent variable is the gap between the average total healthcare expenditure for in kind benefits and the average partial expenditure by age and sex supplied by IGSS.[26] On the right-hand-side of Eq. (D.1), the equation includes the general health status (m), gender (SEX), education attainment (Edu) and three terms with age up-to the third power to fit non-linear expenditure profiles across age.

Table D.1 shows the estimated coefficients of the expenditure mapping function. The gap between average total and partial expenditures diminishes with individuals' age and health status. It is higher for male individuals and those with low educational attainment (not significant effect).

Second, we use the IGSS data to calculate the following proportionality factors, which link average expenditure across age cohorts:

$$\rho_t = \frac{\bar{e}_{t-1}}{\bar{e}_t}, \text{with } t = 1, \ldots, 50, \quad \text{(D.2)}$$

$$\bar{\rho} = \frac{\sum_{t=0}^{49} \bar{e}_t \cdot n_t}{\sum_{t=50}^{99} \bar{e}_t \cdot n_t}, \text{ and} \quad \text{(D.3)}$$

$$\upsilon = \bar{\rho} \cdot \frac{\left(\sum_{t=50}^{99} \hat{e}_t \cdot n_t\right)}{\left(\sum_{t=0}^{49} \rho_t \hat{e}_{t+1} \cdot n_t\right)}. \quad \text{(D.4)}$$

In Eq. (D.2) to (D.4), $\bar{e}_t$ is the average total healthcare expenditure and n_t the number of beneficiaries for age t. Factors in Eq. (D.2) link average total healthcare expenditure in age t to the average expenditure in t-1. The factor in Eq. (D.3) is the ratio of total healthcare expenditure of residents aged below fifty years and those aged fifty and above. Then, we adjust factors in Eq. (D.2) using the multiplicative factor υ in Eq. (D.4).

As a result, Eq. (D.1) allows to calculate the average total healthcare expenditure by age $\hat{e}_t$ for individuals aged fifty and over based on the partial healthcare expenditure (i.e., for all $t \geq 50$). In addition, the proportionality factors in Eq. (D.2) permit to extrapolate average total healthcare expenditure by age for individuals aged less than 50 (i.e., $\hat{e}_t = \rho_t \hat{e}_{t+1}$ for all $t < 50$) and construct the full age profile of average total expenditure. Finally, Eq. (D.3) and the adjustment factor υ in Eq. (D.4) allow ensuring a stable relationship between the total healthcare expenditure of young and old residents.

It is important to notice that the algorithm does not decompose the expenditure between resident and non-resident insured. Therefore, the projections implicitly assume that the relationship between the expenditure profiles (by age and gender) of resident and non-resident insured individuals remain constant as in 2012. In 2012, 32.5% of the insured population was non-resident and its share of in-kind healthcare expenditure was 29% (CNS, 2014). In 2013, non-resident insured individuals remain stable at 32.7% but its share of in-kind expenditure diminished substantially to 19% (CNS, 2014). Likewise, in 2019, non-residents represented 35% of insured population and 17% of in-kind expenditure. These changes result from several factors like social protection system reforms, the economic situation, and the demographic evolution of the full and active population. In particular, IGSS (2020) notes that non-resident insured individuals aged more than 60 years old are still very few, what limits healthcare expenditure. Moreover, only healthcare expenditures by non-resident retired with full career in Luxembourg are covered by the health insurance. Consequently, our medium term

[26] We adjusted it to account for changes in the price level between 2012 and 2019.

projections would overestimate total healthcare expenditure because of excessive expenses by non-resident though this gap should close in the long run.

Table D.1: Estimated coefficients of the expenditure mapping function

Variables	**Benchmark**	**Morbidity compression**
	Coeff. (p-value)	**Coeff. (p-value)**
Age	-4863.2	-4945.8
	(0.000)	(0.000)
Age^2	69.9	71.2
	(0.000)	(0.000)
Age^3	-0.3065	-0.3127
	(0.000)	(0.000)
Individual health status	-8083.7	-9197.8
	(0.0000)	(0.0000)
Gender	657.3	705.8
	(0.000)	(0.000)
Education attaintment	-147.4	-243.8
	(0.500)	(0.319)
Constant	112307.4	114138.8
	(0.000)	(0.000)
R-squared	0.9332	0.9273
Observations	151	151
F(6,144) (p-value)	346.52 (0.000)	336.76 (0.000)

Appendix E: Calculating public expenditure on long-term care

In Luxembourg, the Dependency Insurance Assessment and Control Administration of the Social Security system evaluates each candidate's limitations in daily activities to calculate the hours of aid per week that are required. A candidate is declared *dependent* if this exceeds 3.5 hours per week. Beneficiaries are assigned one of the fifteen dependency levels to ensure sufficient coverage of their assistance needs irrespective of their age.[27]

To calculate public expenditure on long-term care from the health status of individuals in our simulated population, we follow a three-step approach. First, we assess the hours of AEV (activities of daily living) assistance required for each individual aged fifty and over, based on the diseases and limitations in daily activities that we model. We implement a procedure similar to that used by the Dependency Insurance Assessment and Control Administration. Our procedure is somewhat simplified, but covers all five essential acts of life: personal hygiene, elimination, eating, dressing and mobility. We also assume that individuals receive all the benefits to which they are entitled.[28]

Second, we distinguish four groups: nursing home residents, individuals living at home with a professional caregiver (benefits in kind), individuals living at home with an informal caregiver (benefits in cash), and individuals living at home with both professional and informal care.[29]

Finally, and after the first round of simulation, we calibrate the algorithm to fit the number of beneficiaries in each age category as drawn from the Annual Report of the Social Security administration, IGSS (2020). Then, we calculate long-term care expenditure for each dependent individual, accounting for the qualification required, the type of provider and the official 2020 rates.

[27] See https://aec.gouvernement.lu/fr/l-administration.html.

[28] Our approach also considers individuals suffering from deafness, communication disorders, blindness or *spina bifida,* who may not meet the usual dependency criteria but are entitled to a flat-rate cash benefit corresponding to six hours of help and care per week.

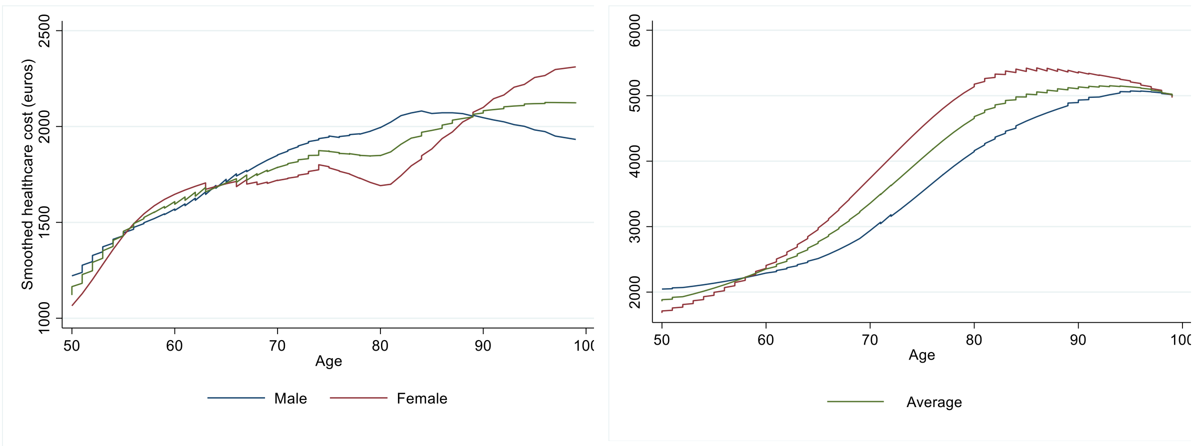
[29] Cash benefits (covering help provided by a relative or a person hired by the beneficiary) replace benefits in kind (provided by a care network) if the dependent person lives at home and the informal carer was registered and evaluated by the Dependency Insurance Assessment and Control Administration. Benefits in cash and in kind can be combined.

Appendix F: Average partial healthcare expenditure by age and gender

In this appendix, we further analyse the gender gap between the average healthcare expenditure by focusing on expenditure associated with a specific set of diseases that are more prevalent among the elderly.[30] Figure F.1 reports the results. Expenditure on women in 2020 is clearly below expenditure on men for individuals between 65 and 90 years but it is above expenditure on men for individuals above 90. Below 65 years of age, there is no significant gender gap. In 2070, expenditure on women is higher than expenditure on men in the range between 60 and 95 years old. The gender gap in partial healthcare expenditure is in line with the Eurostat statistics,[31] which reflect the fact that women tend to live longer but have poorer health. In our model, this is also due by the selected diseases that are more prevalent among women (e.g. depression, dementia, stroke).

Figure F.1: Healthcare (subset of diseases), average expenditure by gender and age in 2020 and 2070 - Benchmark scenario

(a) In 2020 (b) In 2070



Source: Own calculations.

This suggests that it could be important to evaluate the contribution of specific diseases to total healthcare expenditure. Focusing only on total healthcare expenditure can provide a misleading picture of the effects of individual characteristics, undermining the design of health-related policies.

[30] See Appendix D for a list.

[31] See https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Healthy_life_years_statistics.

Appendix G: References for calibrating medical treatments

Variables in the model	References for calibration and treatments
Hypertension	- Scientific council, Health Domain, Luxembourg - Santé.lu (Portail Santé, Grand-Duché de Luxembourg) - Ruiz-Castell et al. (2016) - European Society of Cardiology
Diabetes	- Scientific council, Health Domain, Luxembourg - WHO (2016) - Santé.lu (Portail Santé, Grand-Duché de Luxembourg) - Louazel et al. (2008) - International Diabetes Federation, Diabetes Altlas - European Society of Cardiology
High cholesterol	- Luxembourg Institute of Health - European Society of Cardiology - Lecoffre (2018)
Stroke	- Health Direction, Ministry of Health, Luxembourg - Santé.lu (Portail Santé, Grand-Duché de Luxembourg) - Inserm, Research Institute, France
Pneumonia	- Conseil Supérieur de Maladies Infectieuses, Luxembourg - Country Health Profile, WHO, 2017a
Cancer	- National Institute of Cancer, Luxembourg
Ulcer	/
Parkinson	- Parkinson Luxembourg - National Centre of Excellence in Research on Parkinson's disease, Luxembourg - Santé Publique France (2018)
Cataract	- Directorate of Research, Studies, Evaluation and Statistics (DREES), 2018, Ministry of Solidarity and Health, France
Femur	/
Fractures	/
Alzheimer	- Association Luxembourg Alzheimer - Alzheimer Europe Fondation - Fondation Recherche sur l'Alzheimer, France - Inserm, Research Institute, France - World Alzheimer Report (2015), Alzheimer's Disease International
Anxiety	- Service Information et Prévention de la Ligue, Prévention panique, Ministry of Health
Rheumatism	- Inserm, Research Institute, France - Polyarthritis rheumatoid, Haute Autorité de Santé, France
Arthrosis	- Inserm, Research Institute, France
Kidney	- Alkerwi et al. (2017)
Heart attack	- Alkerwi et al. (2010) - Institut National de Chirurgie Cardiaque et de Cardiologie Interventionnelle (INCCI), Luxembourg - European Society of Cardiology
Hearing	- Santé.lu (Portail Santé, Grand-Duché de Luxembourg)
Depression	- Börsch-Supan et al. (2005) - Lépine and Briley (2011) - Heo et al. (2008) - WHO (2017b) - Service Information et Prévention de la Ligue, Prévention dépression, Ministry of Health
Orientation	/
Memory	- Santé.lu (Portail Santé, Grand-Duché de Luxembourg)
Eyesight	- Santé.lu (Portail Santé, Grand-Duché de Luxembourg)
Dementia	- World Alzheimer Report (2015), Alzheimer's Disease International - Demenz (2013) - Perquin et al. (2015) - Ankri (2006) - Jacqmin-Gadda et al. (2013)

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