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PENELOPE: LUXEMBOURG TOOL FOR PENSION EVALUATION AND LONG-TERM PROJECTION EXERCISES

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PENELOPE: *Luxembourg Tool for*

Pension Evaluation and Long-Term Projection Exercises

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Abstract

This document presents the structure of PENELOPE, a macro-accounting tool aimed at examining the long-run sustainability of the Luxembourg pension system. PENELOPE complements other models studying the Luxembourg pension system by proposing a disaggregated pension analysis in which demographic changes affect macroeconomic variables. The results of PENELOPE's reference scenario are compared with those of other studies, while additional simulations focus on (i) the effects of different population projections and assumptions on cross-border worker inflows, (ii) the implications of the 2012 pension reform and of alternative proposals, as well as (iii) the evolution of the pension reserve under different scenarios.

Keywords: Pension expenditure projections, demographic trends, labor inflows, pension reform

JEL-Codes: H55, H68, J11

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Résumé non-technique

Ce document présente un nouvel outil d'évaluation de la soutenabilité à long-terme du système de pension au Luxembourg, PENELOPE, acronyme pour *Luxembourg Tool for Pension Evaluation and Long-Term Projection Exercises*. Il explique la structure du modèle, discute ses différences par rapport aux modèles existants et détaille les résultats de plusieurs simulations.

D'après le rapport sur le vieillissement de la Commission européenne, le *2018 Ageing Report*, l'augmentation des coûts du vieillissement sur la période 2016-2070 mettra sous pression les finances publiques, notamment à travers la hausse attendue des dépenses de pensions. Parmi les Etats membres, le Luxembourg subira, selon ces projections, la plus forte augmentation des dépenses de pensions par rapport au PIB, qui passeront de 9% en 2016 à 17.9% en 2070.

L'évaluation des dépenses publiques liées au vieillissement dans les *Ageing Report* dépend des projections démographiques d'Eurostat et se fait en deux étapes. Tout d'abord, les effets de la démographie sur l'évolution des variables macroéconomiques (p.ex. l'emploi ou le PIB) résultent d'hypothèses et de méthodes communes entre Etats membres. Ces derniers calculent ensuite les dépenses de pensions avec leur propre outil de modélisation des pensions. Les projections de pensions pour le Luxembourg sont réalisées avec le modèle de pension de l'Inspection générale de la sécurité sociale (IGSS), le National Pension Model (NPM, voir Everard, 2017). Les *Ageing Report* ont donc un objectif ambitieux, qui est de comparer les dépenses de vieillissement entre pays. Cependant, les hypothèses communes sur l'évolution des variables macroéconomiques, rendant comparables les résultats entre pays, empêchent de considérer aisément des scénarios alternatifs propres à chaque pays.

Or, pour une petite économie ouverte comme Luxembourg, certains facteurs extérieurs dont l'évolution est incertaine, comme l'immigration ou l'emploi frontalier, ont des effets importants sur les finances publiques. Ainsi les projections démographiques d'Eurostat publiées dans les *Ageing Report* sont révisées tous les trois ans et dépendent des hypothèses sur l'immigration. Ces révisions influencent fortement les dépenses attendues des pensions. Alors que l'*Ageing Report* de 2012 prévoyait un ratio des dépenses de pensions par rapport au PIB en 2060 de 18.6% avec une population estimée à 0.73 million en 2060, le rapport de 2015 arrivait à un ratio de 13.4% pour une population à 1.10 million en 2060 et le dernier rapport de 2018 à un ratio de 16.0% pour 0.99 million d'habitants en 2060. De même, l'afflux de frontaliers est tout aussi incertain et crucial pour l'analyse de la soutenabilité du système de pension, puisque les frontaliers contribuent grandement au financement du système mais en dépendent aussi lorsqu'ils partent à la retraite. Vu l'importance de ces incertitudes, il est utile de considérer différents scénarios (et modèles) pouvant contribuer chacun à comprendre les

risques sous-jacents aux coûts attendus des pensions au Luxembourg.

La BCL a procédé ces dernières années à de nombreuses analyses sur la soutenabilité du système de pension grâce à son modèle d'équilibre général LOLA (Marchiori and Pierrard, 2015). LOLA modélise l'économie dans son entièreté, prenant en compte divers acteurs (consommateurs, firmes et gouvernement) et secteurs (financier et réel). Il se caractérise par des équations comportementales dans lesquelles les changements démographiques affectent les décisions des agents et donc les variables macroéconomiques. Par contre, le système de pension dans LOLA est agrégé, considérant uniquement les dépenses et contributions totales, mais ne distinguant par exemple pas entre différents bénéficiaires ou entre le régime général dédié au secteur privé et les régimes spéciaux du secteur public.

La première partie de ce document se consacre à la description de PENELOPE, un nouvel outil macro-comptable permettant d'analyser la soutenabilité à long terme du système de pension au Luxembourg. PENELOPE modélise le système de pension en exploitant les données désagrégées de l'assurance obligatoire, ce qui permet, entre autres, de décomposer les dépenses de pensions en différents groupes de bénéficiaires. De plus, l'approche intégrée de PENELOPE prend en compte les effets des évolutions démographiques sur les variables macroéconomiques.

NPM, LOLA et PENELOPE ont chacun leurs spécificités. Par exemple, PENELOPE est moins détaillé au niveau du système de pension que NPM, qui est un modèle comptable calibré à l'aide de données individuelles. Cependant, les répercussions des changements démographiques sur les variables macroéconomiques, incorporées dans PENELOPE, sont évaluées à l'aide d'hypothèses/méthodes externes dans NPM. Du point de vue de la BCL, LOLA et PENELOPE sont des modèles distincts et complémentaires. LOLA a une portée plus vaste que le système de pension, pouvant, en autres, analyser les effets du secteur financier sur la croissance, alors que PENELOPE peut étudier plus en détail le système de pension. Les deux modèles peuvent être utilisés pour comparer des résultats, mais aussi de manière séquentielle. PENELOPE peut ainsi évaluer les effets d'une mesure spécifique, dont l'impact global sur le système de pension sera ensuite utilisé comme hypothèse dans LOLA pour voir les effets sur le reste de l'économie. L'inverse est également possible. Les implications d'une mesure non liée au système de pension peuvent être calculées dans LOLA et servir ensuite dans PENELOPE (par exemple une mesure spécifique au système financier et affectant l'emploi total) pour considérer leurs effets sur certains types de pensions.

La suite du document présente différentes simulations évaluant la soutenabilité à long-terme du système de pension. Une première série de simulations décrit les résultats du scénario de référence de PENELOPE, caractérisé par les hypothèses suivantes: la population évolue selon les projections démographiques de l'*Ageing Report* de 2018 et atteint 0.99 million habitants en 2060, la part des frontaliers dans l'emploi croît de 2016 à 2070 et les mesures de la réforme du système de pension de 2012 s'appliquent aux paramètres de la formule de calcul des pensions. Dans le scénario de référence de PENELOPE, les dépenses de pensions passent de 9% du PIB en 2016 à 18.9% en 2070, alors qu'elles atteignent, en 2070, 17.9% avec NPM et 20% avec LOLA. Bien que s'appuyant sur des méthodologies distinctes, les trois modèles arrivent ainsi à des résultats proches, qui invitent à proposer des mesures afin de garantir la soutenabilité à long-terme du système de pension.

Il est important de mentionner que les projections sont obtenues sous l'hypothèse technique de politique inchangée et qu'elles ne sont donc pas des prédictions, puisque le gouvernement sera amené à prendre des mesures correctrices afin d'éviter une dérive du coût des pensions. L'utilité de telles projections réside donc moins dans les résultats d'un scénario spécifique que dans la comparaison des scénarios entre eux, permettant de comprendre l'effet de certaines hypothèses. Pour cette raison, d'autres simulations, qui modifient certaines hypothèses du scénario de référence, sont considérées.

Une deuxième série de simulations se concentre sur des évolutions alternatives de la démographie et de l'emploi frontalier. Le ratio des dépenses de pensions par rapport au PIB atteindrait 15.8% avec une population à 1.1 million d'habitants en 2070, comme dans l'*Ageing Report* de 2015, et de 20.5% si la proportion de travailleurs frontaliers dans l'emploi restait constante. Une troisième série de simulations se focalise sur la réforme du système de pension. Le ratio des dépenses de pensions par rapport au PIB atteindrait 25% en 2070 si les mesures de la réforme de 2012 n'étaient plus appliquées à partir de 2016 et 15.5% si les pensions n'étaient plus indexées à la croissance réelle des salaires. D'autres simulations évaluent aussi l'impact de la réforme proposée par la Fondation Idea, 'Plan 50+1' (Fondation Idea, 2018). En se basant sur plusieurs individus types, l'étude de la Fondation Idea trouve que, sous une hypothèse de croissance réelle de 3% du PIB, renforcer certaines mesures de la réforme de 2012 (notamment accentuer la baisse de la composante liée aux revenus cotisables et augmenter la hausse de la part fixe de la pension) garantit la stabilité du ratio dépenses de pension sur PIB. PENELOPE confirme ce résultat au niveau macroéconomique, mais montre également qu'avec une croissance du PIB plus faible, la proposition 'Plan 50+1' n'empêcherait pas une dérive du ratio des dépenses de pensions par rapport au PIB. Une dernière série de simulations propose une analyse désagrégée se focalisant sur le régime général des pensions, et notamment sur sa réserve. Dans le scénario central, les dépenses de pensions dépassent les contributions du régime général en 2027 et la réserve atteint le minimum légal, fixé à 1.5 fois le montant des dépenses annuelles, en 2044.

1 Introduction

According to the European Commission's *2018 Ageing Report*, the graying of the population will put Luxembourg public finance under pressure and in particular pension expenditures (EC, 2018). During the coming decades, Luxembourg will experience the largest public pension expenditure increase among European Union (EU) Member States. As shown in table 1, pension expenditures relative to gross domestic product (GDP) are projected to increase by 8.9 percentage points from 2016 to 2070 in Luxembourg and by no more than 3 percentage points in neighboring countries (and would even decrease in France).

Table 1: Projected pension expenditures

	2016 (% of GDP)	2016-2040 (change in pp)	2016-2070 (change in pp)
Luxembourg	9.0%	+2.5 pp	+8.9 pp
Euro Area	12.3%	+1.3 pp	−0.4 pp
France	15.0%	+0.0 pp	−3.3 pp
Germany	10.1%	+1.9 pp	+2.4 pp
Belgium	12.1%	+2.4 pp	+2.9 pp

Source: 2018 Ageing Report of the European Commission (EC, 2018).
pp stands for percentage points.

Eurostat's demographic projections are a major ingredient in the calculation of expected pension expenditures published by the European Commission. Revisions in these population projections have an important impact on projected pension expenditures. This is especially true for a small open economy like Luxembourg, with large immigration and huge cross-border worker flows, whose future evolution is quite uncertain. Table 2 shows how projected pension expenditures to GDP for 2060 have become less worrying in the 2015 Ageing Report compared to the 2012 vintage (a drop from 18.6% to 13.4%) because of a higher expected demographic evolution (from 730'000 to 1.1 million inhabitants in 2060), but have then been revised upwards in the most recent 2018 Ageing Report (to 16.0%) due to a less optimistic demographic growth (around 990'000 inhabitants in 2060).

In the Ageing Reports, the demographic and macroeconomic variables are based on common assumptions and methods for all Member States agreed upon by a group of experts from EU Member States, the Ageing Working Group (AWG). These variables are used as inputs in the calculation of pension projections, which are performed separately by Member States relying on their own national models. This two-step procedure allows an international comparison of the results at the EU level through common assumptions and methodology

Table 2: Luxembourg pension expenditures and population projections

	PE-to-GDP in 2060 (%)	Population in 2060 ('000)	Population projections
The 2018 Ageing Report	16.0%	990	EP15
The 2015 Ageing Report	13.4%	1100	EP13
The 2012 Ageing Report	18.6%	730	EP10

Source: EC (2012, 2015, 2018). PE-to-GDP stands for pension expenditures to GDP. EP15, EP13 and EP10 refer respectively to vintages EUROPOP2015, EUROPOP2013 and EUROPOP2010 of Eurostat's population projections (Eurostat, 2017, 2014, 2011).

regarding the evolution of demographic and macroeconomic variables, while accounting for the country-specific pension legislation through national models. The General Inspectorate of Social Security (*Inspection générale de la sécurité sociale*, IGSS) provides the Luxembourg pension projections for the Ageing Report using the National Pension Model (NPM), an accounting tool with a detailed representation of the pension system based on pension data at the individual level.

Given the uncertainty surrounding the demographic (and macroeconomic) evolution and its impact on pension expenditures, additional analyzes are required to assess the financial health of the Luxembourg pension system. In recent years, LOLA, the general equilibrium model developed at the Central Bank of Luxembourg (*Banque centrale du Luxembourg*, BCL), has served for several analyzes focusing on the sustainability of the Luxembourg pension system (e.g. Bouchet et al., 2017; BCL, 2012b). LOLA models the Luxembourg economy and has therefore a broader scope than NPM. In LOLA, macroeconomic variables, like the labor force or GDP, respond to demographic evolutions or policy changes like pension reforms. However, the pension system is aggregated and does, for instance, not distinguish between the general scheme dedicated to the private sector and the special schemes for the public sector.[1]

This document introduces a tool for disaggregated pension analysis with endogenous macroeconomic variables, PENELOPE: *Luxembourg Tool for Pension Evaluation and Long-Term Projection Exercises*. PENELOPE is a macro-accounting tool centered on the Luxembourg pension system like NPM. It uses disaggregated pension data, decomposing total pension expenditures in different categories of beneficiaries and pension contributions in categories of contributors. As LOLA, PENELOPE is an integrated approach where macroeconomic variables are computed within the model, while NPM relies on macroeconomic outcomes calculated by ex-

[1] Civil servants of the State and municipalities as well as the agents of the national railways have dedicated special schemes (Law of the 3rd of August 1998, see IGSS, 2019).

ternal methods (to comply with the international comparison exercise of the Ageing Report). PENELOPE is therefore a compromise between the two above-mentioned models. Although it is less detailed on the pension side than NPM and less elaborated on the economic side than LOLA, PENELOPE can perform a disaggregated pension analysis unlike LOLA and incorporates demographic-macroeconomic linkages unlike NPM (see section 2 for a discussion).

This document presents several simulations exercises showing how PENELOPE can be used to examine the long-run sustainability of the Luxembourg pension system. The first set of simulations describes the results of PENELOPE's baseline assumptions on the future, in particular concerning demographic changes, cross-border worker dynamics and the pension legislation. In particular, it is considered that population evolves as in the 2018 Ageing Report according to Eurostat's population projections EUROPOP2015 (abbreviated EP15 hereafter), that the share of cross-border workers in employment is rising and that the pension system is subject to the measures of 2012 pension reform. The results of PENELOPE's reference scenario indicate that pension expenditures to GDP rise from 9% in 2016 to 18.9% in 2070. This parallels the findings of NPM and LOLA, where pension expenditures to GDP in 2070 climb to 17.9% and 20%, respectively.

It is important to mentioning that the usefulness of projection exercises resides more in the comparison between scenarios than in the results of a specific scenario, because it allows understanding the implications of a specific assumption on final results. The next exercises relax therefore some of PENELOPE's baseline assumptions. A second set of simulations shows the implications of different vintages of Eurostat's population projections (including the most recent EUROPOP2018 scenario, abbreviated EP18) and of a constant share of cross-border workers in employment. For instance, pension expenditures to GDP in 2070 would reach 15.8% with the more optimistic population growth of the EUROPOP2013 scenario (abbreviated EP13) and 20.5% with a constant cross-border worker share in employment.

A third set of exercises focuses on pension reforms. Pension expenditures to GDP would climb to 25% in 2070 without the measures of the 2012 pension reform, while they could be moderated to 15.5% without indexation of pension levels to real wage growth.[2] Moreover, the simulations evaluate the effects of the alternative reform proposed by the Fondation Idea (2018), the *Plan 50+1*. The *Plan 50+1* suggests a strengthening of some measures implemented by the 2012 pension reform, in particular reinforcing the decrease in the earnings-related part of the pension and its compensation by more marked increase in the non-earnings related component. Indeed, the Fondation Idea (2018) case study finds that its proposal allows keeping pension expenditures of different types of individuals stable over time under a 3% real

[2]These result is based on a scenario in which, when pension expenditures of the general scheme exceed contributions, the indexation of pension levels to real wage growth drops from 1 to 0 (in contrast to the baseline scenario in which it falls from 1 to 0.5).

GDP growth rate hypothesis. Simulations with PENELOPE confirm this result at a macroeconomic level, but do also show that, under a lower growth rate hypothesis, the proposal does not impede expenditures to reach worrying levels. A last set of simulations offers a disaggregated analysis focusing on the general scheme and on the evolution of the mandatory reserve, which has been sustained by surpluses of the general scheme during the last decades. In the baseline scenario, pension expenditures start exceeding pension contributions to the general scheme in 2027 and the reserve reaches the legal minimum in 2044, confirming previous analyzes by the IGSS (see e.g. IGSS, 2018).

The rest of the document is organized as follows. Section 2 compares some features of NPM, LOLA and PENELOPE. The model is introduced in section 3 and the calibration explained in section 4. Section 5 presents the results of the different simulation exercises. Section 6 concludes.

2 Model comparison

This section compares the major features of the IGSS's National Pension Model (NPM) and of the two BCL models used for pension analysis, LOLA and PENELOPE.

The General Inspectorate of Social Security (Inspection générale de la sécurité sociale, IGSS) provides the Luxembourg pension projections for the Ageing Report using the National Pension Model (NPM), which is a version of the International Labour Organization's pension tool adapted to Luxembourg labour market features (Everard, 2017). The NPM comprises a demographic bloc and a financial bloc evaluating pension contributions and expenditures. Since the model is calibrated with individual data available at the IGSS, it allows evaluating the balance of the pension system at a detailed level. However, NPM takes the evolution of macroeconomic variables as given and depends on the demographic and macroeconomic assumptions defined at the EU level (to comply to an international comparison exercise of public expenditures published in the Ageing Reports, see Appendix A for further details).

LOLA models the Luxembourg economy featuring different optimizing agents and sectors (Marchiori and Pierrard, 2015). Households decide whether to consume, save or retire, while firms rent capital and create jobs and the government levies several taxes to finance various expenditures like pension benefits. The model allows studying the pension system in a setting in which macroeconomic variables are endogenous (and only the demographic evolution is exogenous). Any demographic and/or policy change affect agent behavior, which impacts the macroeconomy and thereby the financing of the pension system. Accounting for the behavior and interactions of the different agents in the economy comes at the expense of a less detailed pension system, modeled as an aggregate considering total pension expenditures and contributions but without, for instance, distinguishing between the general scheme for the private sector and the special schemes for the public sector characterizing the Luxembourg pension system.[3]

PENELOPE comprises three main blocs: pension expenditures, pension contributions and production. Pension expenditures and contributions are decomposed into different groups of beneficiaries and contributors. The model is calibrated to match, for given year, official statistics on e.g. the size and average pension of each beneficiary group and subsequently simulated to look at the long-term sustainability of the pension system. PENELOPE does not exploit individual data (see NPM), but, in contrast to LOLA, the structure of its pension system is disaggregated enough to focus on measures affecting only one type of recipients or one type of pension scheme. PENELOPE's production side is characterized by an aggregate production function describing how demographic changes and cross-border inflows affect the labor supply and thereby GDP. In contrast to LOLA, PENELOPE does not model the whole economy nor are its equations based on agent behavior (e.g. labor supply depending on households' labor participation decisions). Nevertheless, PENELOPE's economic side features the essential elements to address questions on the sustainability of the pension system in an integrated framework (unlike NPM).

Table 3: Comparison of three models used for pension analysis

	Model *Institution*	NPM *IGSS*	LOLA *BCL*	PENELOPE *BCL*
1	Luxembourg pension analysis	yes	yes	yes
2	Disaggregated analysis	yes		yes
3	Individual data	yes		
4	International comparison	yes		
5	Integrated approach		yes	yes
6	Scenario design		yes	yes
7	General equilibrium		yes	

Table 3 offers an overview of major features of the three models employed for the analysis of the Luxembourg pension system (line 1 in the table). Both NPM and PENELOPE are characterized by a disaggregated structure of pension pension (line 2), which permits comparing the evolution of the general and special schemes of the pension system or looking at specific groups of pensioners. This said, NPM can provide detailed results through the access to individual level data (line 3). NPM does also comply with AWG assumptions concerning the evolution of macroeconomic variables and its results can therefore be compared with those of other EU countries (line 4). However, it is less straightforward to evaluate alterna-

[3]LOLA features beneficiaries differing "only" by age, by normal and early-retirement status and by the residence during their work-life (resident or cross-border workers).

tive scenarios that involve changes in macroeconomic variables, because these changes need to be computed by external modules.[4] LOLA and PENELOPE follow an integrated approach where endogenous macroeconomic variables react to various changes (demography, policy, productivity,...) without requiring additional tools (line 5). This also allows some flexibility in the scenario design and thus assessing alternative scenarios straight away (line 6). Finally, LOLA is the only model featuring general equilibrium effects (line 7), i.e. capturing changes in the behavior of economic agents and interactions between agents, and can also be used for analyzes beyond pension evaluation like the effects of income tax reforms on employment, public deficit, GDP growth or welfare (see e.g. BCL, 2012a; Marchiori and Pierrard, 2017).

From the BCL's point of view, LOLA and PENELOPE are distinct tools with complementary aspects. While LOLA has a broader scope than PENELOPE and can address issues that go beyond the pension system (e.g. look at the impact of the demand of financial services on GDP), PENELOPE can investigate the pension system in more detail than LOLA (e.g. focus on the financial health of the general scheme, see section 5.4). Nevertheless, LOLA and PENELOPE can be used to compare results related to the aggregate pension system and can also be employed in combination to assess the consequences of specific policy measures. For instance, PENELOPE can evaluate the effect of a specific measure (concerning one type of beneficiaries or only one pension scheme), whose total impact on the pension system can subsequently serve as an hypothesis in LOLA to examine the implications for macroeconomic variables like consumption, investment or welfare. The reverse is also possible. For example, the consequences of an event affecting the financial sector can be first analyzed with LOLA, while PENELOPE can use the impact on total employment computed in LOLA to look at specific aspects of the pension system.

3 Model

PENELOPE is structured around three main blocs: pension expenditures, pension contributions and production. They are presented in turn.

3.1 Pension expenditures

Pension expenditures are the major bloc of the model and can be decomposed into pension expenditures for each type of beneficiaries. This decomposition is described first, before explaining the evolution of the number of beneficiaries belonging to different groups and the calculation of the average pension of the members of each group.

[4] Note that the alternative scenarios published in the Ageing Report (and evaluated for Luxembourg through the NPM) are common to all EU Member States and have been agreed upon by the AGW group.

Decomposing pension expenditures

Data from the IGSS, Eurostat and the Ageing Reports are used to classify pension expenditures, and in particular beneficiaries, according to the following criteria. First, beneficiaries belong either to the general scheme dedicated to the private sector (*régime général*) or to the special schemes for the public sector (*régimes spéciaux*). Moreover, pensions are paid out to residents but also abroad to non-resident retirees, with a distinction between cross-border (living in neighboring country) and emigrated retirees (living in a non-neighboring country). Pensions also differ according to the retirement age of the recipient i.e. whether the retiree benefits from a legal age or an anticipated pension. Finally, some recipients may receive old-age pensions (*vieillesse*), while others are entitled to disability pensions (*invalidité*) or to survival pensions (*survie*) for widow/widower or orphans.

Note that the residence distinction allows taking on board differences in labor market characteristics between resident, emigrated and cross-border recipients with an impact on the financing of pensions. For example, cross-border workers have generally shorter careers in Luxembourg than resident workers. Moreover, one focus of the analysis is to look at alternative scenarios of cross-border worker inflows on the financing of pensions and not dividing pensions paid abroad into cross-border and emigrated groups would overestimate pensions paid to cross-border retirees.

In each year t, pension expenditures (PE) depend on the number of beneficiaries (B) and on the average pension (P) of each type of recipient in the following manner

$$PE_{hijk,t} = P_{hijk,t} \cdot B_{hijk,t} \tag{1}$$

Equation (1) considers the following breakdown in beneficiary categories h, i, j, k

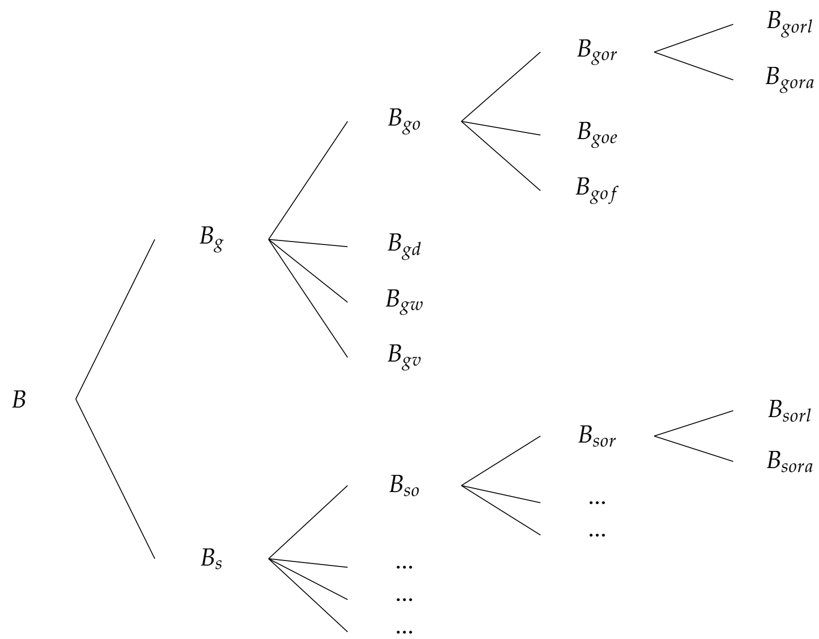
- h=$\{g, s\}$ with g=general scheme, s=special schemes
- i=$\{o, d, w, v\}$ with o=old-age, d=disability, w=survival-widowers, v=survival-orphans
- j=$\{r, f, e\}$ with r=resident, f=cross-border, e=emigrated
- k=$\{l, a\}$ with l=legal age, a=anticipated

Figure 1 illustrates this classification. For instance, B_{gorl} stands for the number of general scheme (subscript h=g) old-age pensions (subscript i=o) obtained by resident beneficiaries (subscript j=r) at legal age (subscript k=l), while B_g represents the total number of recipients from the general scheme.

Beneficiaires

The number of beneficiaries in each category is calibrated to match the official numbers provided by the IGSS at the initial date of the simulations (see section 4). The next paragraphs

Figure 1: Classification of pension beneficiaries



Among the total number of beneficiaries, B, only B_g belong to the general scheme and only B_{go} obtain an old-age pension. Moreover, among the number of resident beneficiaries entitled to an old-age pension from the general scheme, B_{gor}, only B_{gorl} receive it at legal age. The decomposition is similar for the other groups.

explain the intuition behind the evolution of the number beneficiaries (Appendix B exposes the equations governing the dynamics of the number of recipients). The focus is on the residence of beneficiaries (resident, emigrated and cross-border) and their retirement age (legal age and anticipated pensions).

The legal retirement age in Luxembourg is 65, while an anticipated pension can be claimed earliest at the age of 57 for a retiree with at least 40 contributory years (CNAP, 2019). The evolution of the resident population aged 65+, which is given by Eurostat's demographic projections, is therefore an important driver of the number of resident beneficiaries of legal age pensions, while it is assumed that the evolution of the resident population aged 55 to 64 projected by Eurostat and of the labor force participation of this age class determine the number of beneficiaries of anticipated pensions. The total number of resident pension beneficiaries,B_r, is thus given by the sum of legal age and anticipated pension recipients $B_r = B_{rl} + B_{ra}$. The dynamics of the number of emigrated beneficiaries, B_e, i.e. individuals in non-neighboring countries entitled to Luxembourg pensions, follows the one of their resident peers.

The evolution of the number of cross-border beneficiaries is one reason advocated for the good health of the Luxembourg pension system because cross-border workers contribute (currently) more to the system than they benefit from it. Cross-border beneficiaries (subscript j=f) are defined as individuals living in neighboring countries and entitled to a Luxembourg pension. The total number of cross-border beneficiaries, B_f, is described by

$$B_{f,t} = \frac{\gamma_{B,t}}{1 - \gamma_{B,t}} \left(B_{r,t} + B_{e,t} \right) \tag{2}$$

where B_r and B_e represent the total number of resident and emigrated beneficiaries, respectively and $\gamma_B \in [0, 1]$ is the share of cross-border retirees among all beneficiaries. The dynamics of fraction γ_B is an important driver of cross-border pension expenditures and depends on the evolution of cross-border workers (see discussion in section 4).

The following equation allows determining the number of cross-border beneficiaries of anticipated pensions (subscript k=a) from any scheme and any pension-type

$$B_{fa,t} = \mathcal{F}(\gamma_{B,t}\,,\, Z^{5564}_{f,t}) \tag{3}$$

where Z^{5564}_{f} is the number of potential cross-border beneficiaries aged 55-64, i.e. cross-border individuals aged 55-64 who are working or have worked in Luxembourg. Some of these individuals, a fraction $b_{fa} \in [0, 1]$, are entitled to Luxembourg pensions. The initial value of b_{fa} is calibrated to match the number of cross-border recipients of anticipated pensions in the data, while its evolution is determined by the dynamics of γ_B. Function $\mathcal{F}$, derived in Appendix B, is increasing in its arguments and thus equation (3) states that B_{fa} depends positively on γ_B and on Z^{5564}_{f}. Given the two equations above, the number of cross-border beneficiaries entitled to pensions at legal age is simply $B_{fl,t} = B_{f,t} - B_{fa,t}$. The evolution of the number of individuals belonging to more disaggregated cross-border beneficiary groups is then similar to the evolution of corresponding resident beneficiary groups.

Annual pension

As mentioned above, P_{hijk} is the average pension of beneficiaries belonging to group *hijk*. The next lines focus on the calculation of old-age pensions of the general scheme, though the formulas used to compute the other types of pensions share similar features and are discussed later (see also Bouchet et al., 2014; Everard, 2017). The annual pension can be decomposed as follows (category subscripts *hijk* are dropped for ease of exposition)

$$P_t = \phi_t \cdot \lambda_t \cdot (P_{1,t} + P_{2,t} + P_{3,t} + P_{4,t}) \tag{4}$$

Equation (4) comprises two earnings related terms (P_1, P_2), two non-earnings related terms (P_3, P_4) and two adjustment factors (ϕ, λ). The components P_1 to P_4 are determined next. The so-called pro-rata enhancement (*majoration proportionnelle*) of the pension, P_1, is directly proportional to work-life income

$$P_{1,t} = p_{1,t} \cdot LifeInc_t \tag{5}$$

where p_1 is a pension parameter and $LifeInc$ represents work-life income, i.e. the sum of contributory earnings (*cumul des revenus cotisables*).

The incremental pro-rata enhancement (*majoration proportionnelle échelonnée*), P_2, is governed by

$$P_{2,t} = \max\{0, RetAge_t + ContY_t - p_{2a,t}\} \cdot p_{2b,t} \cdot LifeInc_t \tag{6}$$

P_2 is also increasing in the retiree's total contributory earnings but also in her/his retirement age, $RetAge$, and contributory years, $ContY$, with the aim to spur labor participation.

The lump-sum enhancement (*majoration forfaitaire*), P_3, is given by

$$P_{3,t} = p_{3,t} \cdot \frac{\min\{40, QualY_t\}}{40} \cdot MinInc \tag{7}$$

where p_3 is a parameter, $MinInc$ is the social minimum income (*revenu minimum social*) and $QualY$ represents qualifying years, which include contributory years, $ContY$, and credited non-contributory years (such as the years spent raising children or studying).

Finally, the equation describing the end-of-year allowance (*allocation de fin d'année*), P_4, is similar to the previous equation

$$P_{4,t} = p_4 \cdot \frac{\min\{40, QualY_t\}}{40} \cdot MinInc \tag{8}$$

where p_4 is a parameter.

Note that p_1-p_4, ϕ, λ and $MinInc$ are set by law and vary over time, except p_4 and $MinInc$ (which is indicated by the absence of time subscript). Components P_3 and P_4 are, unlike P_1 and P_2, the same for two retirees with different work-life income but identical in every other aspect, such as career start or career length. Moreover, $RetAge$, $QualY$, $ContY$ and $LifeInc$ depend on recipients' career and are averages over the members of a beneficiary group (thus category subscripts *hijk* apply to $RetAge$, $QualY$, $ContY$ and $LifeInc$ as well as to P and P_1-P_4 but not to p_1-p_4, ϕ, λ and $MinInc$).[5]

$LifeInc$ and $MinInc$ are expressed in the price level of 1948 and in the real wage level of 1984, which in the case of $LifeInc$ allows assigning an equal weight to all work-life earnings in the calculation of the pension. Factors ϕ and λ ensure the updating of pensions at current price and real wage levels. ϕ depends on the price evolution (inflation), which is assumed constant, while λ evolves with real wage growth, but this correspondence can be adjusted downwards if the health of the pension system deteriorates (see section 4 and Appendix D).

Finally, old-age pensions of the general and special scheme are calculated in the same way,

[5]While $RetAge$, $QualY$, $ContY$ and $LifeInc$ are constant in the calculation of a single recipient's pension, they may vary over time when computing the average pension of beneficiaries of a given group, since new members have different features than exiting members.

while the formula of disability and survival pensions feature similar pro rata and flat rate enhancements as old-age pensions (IGSS, 2019).[6]

3.2 Pension contributions

Pension contributions, PC, depend on the contribution rate (τ), the average nominal wage (w) and the number of contributors (C)

$$PC_{hjz,t} = \tau_t \cdot w_{hjz,t} \cdot C_{hjz,t} \tag{9}$$

Contributors are broken down into categories j, k and z, where j denotes the scheme to which individuals contribute, k the residence of contributors and z their labor market status.

- h=$\{g, s\}$ with g=general scheme, s=special schemes
- j=$\{r, f\}$ with r=resident, f=cross-border
- z=$\{n, u, x\}$, with n=employed, u=unemployed on benefit (*chômeur indemnisé*), x=others (e.g. voluntary contributors)

For instance, C_{grn} stands for the number of resident employed general scheme contributors.

3.3 Economic growth

It is assumed that the working age population is made up of individuals aged 15 to 64 years. Employment comprises resident and cross-border workers, aged 15 to 64, $N^{1564} = N_r^{1564} + N_f^{1564}$. In what follows, the age superscript referring to age class 15-64 is dropped in all the variables for brevity.

Resident employment is defined by

$$N_{r,t} = Z_{r,t} \cdot \ell_{r,t} \cdot (1 - \mu_{r,t})$$

where Z_r is the resident working age population, ℓ_r is the labor force participation rate and μ_r the unemployment rate of the 15-64 age class.

The number of cross-border workers are derived from

$$N_{f,t} = \frac{\gamma_{N,t}}{1 - \gamma_{N,t}} N_{r,t} \tag{10}$$

[6]The same old-age pension formula as in the general scheme is used to calculate the pensions of persons who entered the public sector since 1999. For retirees who joined the public before 1999, the pension is calculated based on a rate of 5/6 their last salary for the years before 1999 and on a gradually downward adjusted rate (from 83.33% to 72%) for the years of service since 1999. The rates and periods used in the calculation of the components P_1 to P_4 of disability and survival pensions are different than those used to compute old-age pensions.

where $\gamma_N \in [0,1]$ is the (exogenous) share of cross-border workers in total employment.

Consider a standard Cobb-Douglas production function with constant returns to scale

$$Y_t = A_t K_t^{\alpha} N_t^{1-\alpha}$$

where Y represents output in real terms, A productivity, K capital, N employment and α the constant capital share in production. Assuming a constant capital-to-labor ratio leads to the following annual output growth rate (see Appendix C for details)

$$g_{Y,t} = g_{A,t} + g_{N,t} \tag{11}$$

where g_A is productivity growth rate and g_N the employment growth rate.[7] Equation (11) captures the effects of demographic changes but also of cross-border inflows on economic growth through employment growth. Indeed g_A is assumed exogenous, while g_N depends on the evolution of N_f and N_r. The number of cross-border workers, N_f, is influenced by the exogenous proportion of cross-border workers in total employment, see equation (10), and by resident employment, N_r, itself depending on the demography, the labor force participation rate and the unemployment rate.

3.4 Reserve of the general scheme

The general pension scheme is characterized by the mandatory accumulation of a reserve fund, R_g. The reserve is sustained by the surpluses of the general pension scheme and the interest incomes resulting from investments in financial markets (mutual funds).[8] More precisely, the reserve dynamics are given by

$$R_{g,t} = (1 + i_t) R_{g,t-1} + \Gamma^*_{g,t} \tag{12}$$

where i is the nominal interest rate earned on financial market investments and Γ^*_g is an extended balance with $\Gamma^*_g > 0$ indicating a surplus and $\Gamma^*_g < 0$ a deficit. Moreover, $\Gamma^*_{g,t} = \Gamma_{g,t} + \epsilon_C PC_{g,t}$ and equals the annual balance of the general scheme, Γ_g, plus extra resources (revenues from capital assets, transfers from other institutions, ...), expressed as a share ϵ_C of pension contributions to the general scheme, PC_g.

The annual balance of the general pension scheme results from

$$\Gamma_{g,t} = PC_{g,t} - (1 + \epsilon_E) PE_{g,t}$$

[7] A constant capital-labor ratio is compatible with a fixed interest rate like under a small open economy assumption, see also LOLA. Note also that this assumption is different from assuming capital to grow at the same rate than output, as is usually the case when the economy is on a balanced growth path (and population grows at a constant rate). Here, the analysis focuses on the period 2016-2070, where population growth is not constant and varies according to Eurostat's population projections.

[8] General scheme pensions are paid by the National Pension Insurance Fund (CNAP, *Caisse nationale d'assurance pension*) and the reserve is managed by the Compensation Fund (FDC, *Fonds de compensation*). In the case where contributions are insufficient to finance pensions, the FDC can use the reserve to provide the necessary resources to the CNAP (IGSS, 2019, p.157).

and equals PC_g minus annual pension expenditures, PE_g, augmented by other expenses like administration expenses expressed as a fraction of expenditures, $\epsilon_E PE_{g,t}$. By law, the reserve needs to be sufficiently large to ensure the financing of one and a half times the total amount of annual pension expenditures of the general scheme, i.e. $R_{g,t} > R_{g,t}^{min} = 1,5 \cdot PE_{g,t-1}$, with R_g^{min} the minimum reserve level.

Finally, note that a negative balance can activate measures aimed at guaranteeing the good financial health of the system. In particular,

$$\Gamma_{g,t} < 0 \quad \Leftrightarrow \quad \frac{PE_{g,t}(1+\epsilon_E)}{w_{g,t}\, C_{g,t}} < \tau_t \tag{13}$$

where w_g is the average public sector wage and C_g the number of contributors to special schemes. The ratio on the left-hand-side of the second inequality in condition (13) is called the pure sharing premium (*prime de répartition pure*). Condition (13) states that a negative $\Gamma_{g,t}$ is equivalent to a pure sharing premium being smaller than the contribution rate τ, which as foreseen by the 2012 reform, triggers a slow down of the pension revaluation (through a lower growth of λ) to dampen pension expenditures (see section 4).

4 Calibration

This section presents the calibration of the model reproducing the current state of the Luxembourg pension system. It then describes the baseline assumptions made on the future. These assumptions concern, for instance, demographic changes and cross-border worker inflows over the period 2016-2070 and characterize PENELOPE's reference scenario on the long-term evolution of the pension system. Section 5 discusses the results from PENELOPE's baseline scenario, but also from alternative scenarios based on departures from these baseline assumptions.

4.1 Calibration and data sources

The model is calibrated to match pension and marcoeconomic indicators for a specific year and then simulated at an annual frequency. In particular, the values of the different parameters and exogenous variables are chosen so as to reflect the Luxembourg economic conditions and especially the financial situation of the Luxembourg pension system in the year 2016, which is the reference year of the projections published in the latest Ageing Report (EC, 2018). Table 4 provides a summary of the calibration reporting the values of selected parameter and exogenous variables.

Population and labor force. Table 4 shows that, according to STATEC (2019), total population in 2016 equals 576'200 persons, with 399'400 thousand individuals aged 15 to 64 and 82'000 aged 65+ (in rounded numbers). In 2016, total employment (*emploi intérieur*) comprises

418’400 workers with 249’800 resident workers (*emploi national*) and thus the share of cross-border workers in employment, γ_N, is 40.3%. Moreover, the unemployment rate, μ_r^{1564}, is 6.4%, given 17’000 resident individuals are unemployed, and the share of public sector resident employment, ρ_r^{1564}, is 20.5%. According to the data from the OECD (2019), the labor force participation share of the 55-64 age class, ℓ_r^{5564}, equals 40.4%. Finally, using the values for μ_r^{1564}, N_r^{1564} and Z_r^{1564}, the resident labor force participation rate of the 15-64 age class is calibrated to 66.8%.

Table 4: Selected variables in 2016

Labor market		**Pension parameters**	
Z_r^{1564} ('000)	399.4	p_1	1.825%
Z_r^{65+} ('000)	82.0	p_{2a}	93.7
N^{1564} ('000)	418.4	p_{2b}	0.01%
N_r^{1564} ('000)	249.8	p_3	23.95%
γ_N	40.3%	p_4	2.5%
μ_r^{1564}	6.4%		
ρ_r^{1564}	20.5%	**Others**	
ℓ_r^{1564}	66.8%		
ℓ_r^{5564}	40.4%	ρ_r^{65+}	11.7%
		γ_B	29.4%
General pension figures		$RetAge_g$	60.2
		ϕ	7.7517
PE (w.r.t. GDP)	9.0%	λ	1.413
PC (w.r.t. GDP)	9.5%	τ	24.0%
GDP (bn euros)	54.2	i	5.0%
C ('000)	191.1	ϵ_E	5.7%
B ('000)	435.5	ϵ_C	0.9%

Pension system. According to the 2018 Ageing Report (EC, 2018), total pension expenditures and contributions to GDP amount to 9.04% and 9.54% in 2016, respectively, with a GDP of 54.19 billion euros (see also table 4). Moreover, the number of total beneficiaries (B) and contributors (C) equals 191’087 and 435’526, respectively.[9] This information combined with the general scheme data published in the IGSS (2017) report allows deriving special scheme pension expenditures (PE_s), beneficiaries (B_s), contributions (PC_s) and contributors (C_s). It is straightforward to obtain the average pensions for the total system, P, the general scheme, P_g, and the special schemes P_s.

Pension beneficiaries. The IGSS (2017) report provides the average pension levels and numbers of beneficiaries according to the pension-type (old-age, disability, survival-widowers,

[9]Data obtained from the IGSS.

survival-orphans), the retirement age (legal age, anticipated) and the residence (resident, cross-border, emigrated). For instance, 53% of the old-age general scheme pensions are paid to resident, 32.6% to cross-border and 14.4% to emigrated retirees. The groups for special schemes are deduced by combining these data with the total pension system data included in the Ageing Report. This procedure leads to a share of resident individuals aged 65+ entitled to a public pension, ρ_r^{65+}, of 11.7% and to a share of cross-border retirees among all beneficiaries, γ_B, of 29.4%.

Pension contributions. The calibration of C, C_g and C_s is explained above. The number of cross-border contributors (C_f) is assumed to be equivalent to the number of cross-border workers (a small fraction of whom are public sector contributors). It is then possible to compute the resident contributors (as well as C_{gr} and C_{sr}). The contribution rate to the pension system equals 24%. The average income for the different contributor groups is obtained to match the corresponding pension contributions.

Table 5: Pension system 2016, selected statistics

Panel A: Total pension system			
Pension expenditures to GDP (PEY, %)		Beneficiaries (B, '000)	
Total (PEY)	9.04	Total (B)	191
General scheme (PEY_g)	7.00	General scheme (B_g)	173
Special schemes (PEY_s)	2.04	Special schemes (B_s)	18
Panel B: General pension scheme			
Pension expenditures (% of PE_g)		Beneficiaries (% of B_g)	
Resident	72.6	Resident	53.2
Cross-border	18.9	Cross-border	32.3
Emigrated	8.5	Emigrated	14.5

Source: IGSS (2017), 2018 Ageing Report (EC, 2018) and own calculations.

Pension formula. The initial values for parameters p_1 to p_3 are set to their 2016 values. Moreover, p_4 is constant and equals 0.025, while the official 1984 reference level for the annual minimum income, $MinInc$, equals 2085 euros (see CNAP, 2019). The average values of $RetAge$, $QualY$ and $ContY$ associated to the different beneficiary groups are computed using data from the IGSS report. For instance, calculations lead to a general scheme average for $RetAge$ of 60.2. It is then possible to calculate P_3 and P_4. The cost of living index ϕ prevailing in 2016 is 7.7517. The revaluation factor λ is computed as the weighted average over the values for individuals retired in 2013 and before (weight 37/40), in 2014, in 2015 and in 2016 (each a weight of 1/40). Finally, $LifeInc$ appears in P_1 and P_2 and is calibrated such that the pension resulting from the formula in equation (4) matches the data. Data indicate that the parameters ϵ_E and ϵ_C linked to the computation of balance general regime vary little over the past years years and they are therefore assumed constant to $\epsilon_E = 5.7\%$ and $\epsilon_C = 0.9\%$. The nominal return of investing the reserve on financial markets i is set to 5%, which is in accordance with the average 4.9% nominal return over the period 2007-2017 reported by Bouchet (2018).

Finally, table 5 gives an overview of the pension system in 2016. Panel A shows the importance of the general scheme in the total pension system in terms of expenditures and beneficiaries. Panel B zooms into the general scheme and indicates that resident retirees are the main beneficiaries and weigh the most in terms of pension expenditures.

4.2 Baseline assumptions on the future

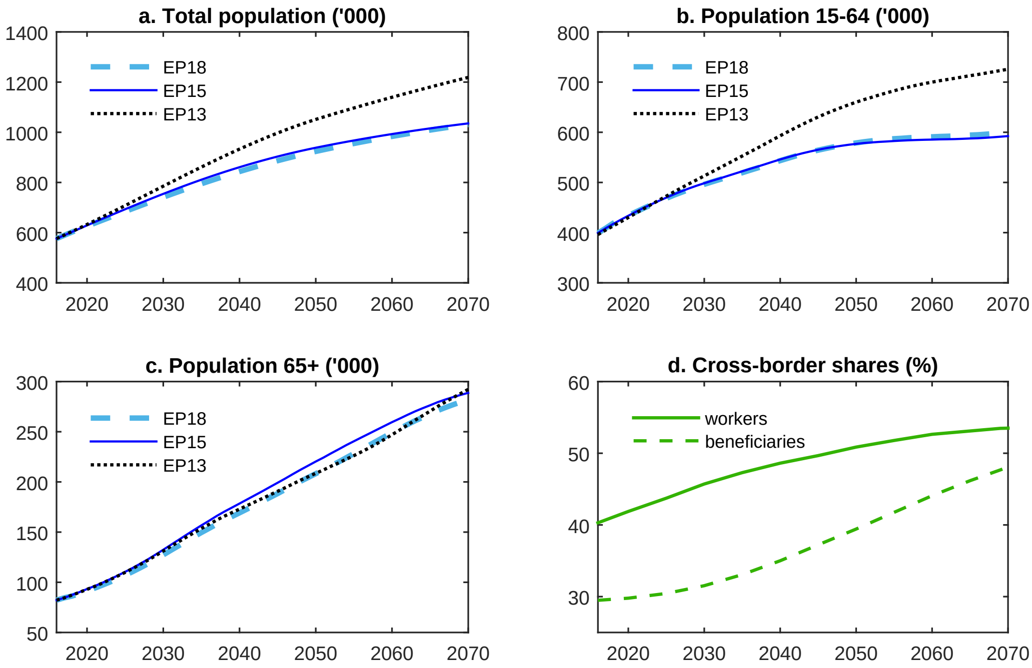
The analysis focuses on the period from 2016 to 2070, following the most recent Ageing Report (EC, 2018). Table 6 provides an overview of the baseline assumptions on the future characterizing PENELOPE's reference scenario.

Demographic changes and cross-border worker inflows

The resident population evolves according to Eurostat's population projections affecting in particular the working age population, Z_r^{1564}, as well as the age class 65+, Z_r^{65+}. The central demographic scenario of Eurostat's population projections EP15 (Eurostat, 2017) are chosen for the baseline scenario of the present study, because they are also the underlying demographic assumptions of the simulations performed with the NPM model and published in the most recent Aging report (EC, 2018). Nevertheless, results are also delivered for two other vintages, the most recent EP18 (Eurostat, 2019) and the older EP13 population projections (Eurostat, 2014).

Figure 2 shows how different groups of resident individuals are expected to change according to these three vintages. It displays the evolution of the total population (panel *a*), the working age population (panel *b*) and the age class 65+ (panel *c*). Overall, projections EP18 and EP15 are close to each other, though the former is slightly more optimistic than the latter, but both are less optimistic than projections EP13. Total population (panel *a*) rises from 576'000 in 2016 to above one million in 2070 in the three vintages (1.04 million in EP18, 1.03 million in EP15 and 1.22 million in EP13). The working age population (panel *b*) climbs to around 600'000 in 2070 according to the EP18 and EP15 population projections and to 726'000 in the EP13 projections. The senior population (panel *c*) is close in the three vintages. The 65+ population is lowest in the EP18 projections with 282'000 inhabitants in 2070, while EP15 senior population is slightly above the other two during almost the whole period (except in

Figure 2: Demographic assumptions



Panels *a*, *b* and *c* report population in thousand inhabitants. EP18, EP15 and EP13 refer respectively to Eurostat's demographic projections EUROPOP2018, EUROPOP2015 and EUROPOP2013 (Eurostat, 2019, 2017, 2014). Panel *d* presents the proportion of cross-border individuals among workers (γ_N) and pension beneficiaries (γ_B).

2070, where it is joined by the EP13 senior population).

Panel *d* of figure 2 indicates that the share of cross-border workers in employment, γ_N, is assumed to increase over the whole period, climbing from 40.3% in 2016 to 53.5% in 2070. This evolution is borrowed from LOLA's baseline scenario and is consistent with a moderate expansion of the financial sector activity. An alternative scenario will be evaluated in which γ_N remains constant over time at 40.3%, an assumption underlying the pension projections for Luxembourg published in the Ageing Report (EC, 2018).[10] Panel *d* also depicts the evolution of the share of cross-border beneficiaries, γ_B. Cross-border workers are younger on average than resident workers and contribute more to the pension system than they benefit from it. This discrepancy should progressively reduce as more and more cross-border workers reach retirement age. In NPM's reference scenario, it vanishes as it is considered that the benefit ratio of cross-border equals the one of resident workers at the end of the projection

[10]In the Ageing Reports, the labor market impact of cross-border worker inflows is accounted for by an adjustment of labor market participation rates rather than by the number of workers. Indeed, employment refers only to residents and represents around 59% of the number of contributors during the simulation horizon (see also Everard, 2017, table 16).

horizon.[11] In PENELOPE's reference scenario, there is only a partial catch-up of γ_B on γ_N because the proportion γ_N continues increasing and thus cross-border workers continue contributing more to the pension system than residents. In particular, γ_B follows a rule such that the initial γ_N-γ_B gap in 2016 is reduced by half in 2070 (see Appendix E). However, applying the same rule in the alternative scenario assuming a constant share of cross-border workers leads to an almost closing of the gap, which is in line with NPM's reference scenario.

Productivity and labor market

Productivity is assumed to grow at an annual constant rate, $g_A = 1\%$, which affects the GDP growth rate as well as the revaluation factor λ. Prices grow at a constant rate of 2% which influences the cost of living index ϕ. The nominal return of investing the reserve on financial markets is kept at 5%, which corresponds to a real return of 3% given the assumption on inflation. The public employment share is assumed constant, as well as the unemployment rate.

Table 6: Assumptions on the future (2017-2070)

Item	*Concerned variables*	*Assumption*
Population projections	Z_r^{1554}, Z_r^{5564}, Z_r^{65+}	EUROPOP2015
Cross-border worker share	γ_N	tends to 53.5% in 2070
Cross-border beneficiary share	γ_B	evolution with γ_N
Productivity growth	g_A	constant at 1%
Cost of living index	ϕ	growing at rate 2%
Public employment share	ρ_r^{1564}	constant at 20.5%
Unemployment rate	μ_r^{1564}	constant at 6.4%
Labor force participation	ℓ_r^{1554}	constant at 72%
Senior LF participation	ℓ_r^{5564}	rising to 42.5%
Pension formula	p_1, p_{2a}, p_{2b}, p_3, λ	2012 pension reform

Labor force participation

It is not unreasonable to consider a rising senior worker labor participation. Indeed, the discussion so far mentioned the aging of the Luxembourg population projected by Eurostat, while the 2012 pension reform introduced specific measures aimed at encouraging labor market participation of senior workers (see below). Moreover, general equilibrium models

[11] In particular, cross-border individuals have a low career length in Luxembourg at the beginning of the projection horizon and, as they work less abroad, they reach a complete career in Luxembourg at the end of the projection horizon (Everard, 2017, p.12-13). More specifically, the benefit ratio, i.e. the pension expenditures per pensioner divided by GDP per contributor, will be the same for resident and cross-border individuals by 2070.

typically show that increased life expectancy as well as less generous pension benefits discourage early retirement (de la Croix et al., 2013; Diaz-Gimenez and Diaz-Saavedra, 2009; Marchiori et al., 2017). The effective retirement age, $RetAge$, which stands currently around three years below the European average, is assumed to augment by 2 years between 2016 and 2070. This is a weak assumption, since the resulting effective retirement age would remain three years below the European average projected for 2070 in the 2018 Ageing Report (EC, 2018). The participation rate of the 55-64 age class increases from 40.4% to 42.5% between 2016 and 2070.[12] $QualY$ and $ContY$ are increasing in accordance with this evolution as well as $LifeInc$, see Appendix F.

Implications of the 2012 pension reform

The 2012 pension reform includes various measures.[13] The pension reform is meant to ensure the long-term sustainability of the system by gradually reducing its generosity and by encouraging labor market participation (and thus linking active working period to increased longevity). Some of these measures consist of gradual changes, from 2013 to 2052, in the parameter values of the pension formulas (5)-(8):

a. p_1 decreases linearly from 1.85% in 2012 to 1.60% in 2052 (and afterward)

b. p_{2a} increases linearly from 93 in 2012 to 100 in 2052

c. p_{2b} increases linearly from 0.01% in 2012 to 0.025% in 2052

d. p_3 increases linearly from 23.5% in 2012 to 28% in 2052

The reform affects, through parameters p_1, p_{2a} and p_{2b}, the earning-related terms of the pension. *Measure a* makes the pension system less generous by decreasing the pension component depending only on contributory income, P_1. This reduced generosity is mitigated by the conditional increase described by *measure c*, which states that the earning-related term, P_2, increases if the sum of the retirement age and of the contributory years exceeds a given number, though this threshold is rising over the period 2013-2052 as indicated by *measure b*. Moreover, *measure d* leads to a conditional increase in the non-earnings related term P_3, i.e. the lump-sum component augments if qualifying years exceed 40. *Measures c* and *d* are meant

[12]Note, however, that composition effects lead to a moderately decreasing labor participation rate of the 15-64 age class from 66.8% in 2016 to 66.1% in 2070 (see also the Ageing Report EC, 2018). Indeed, the population 55-64 is growing stronger than the one of other age groups and, although the labor participation rate of the age class 55-64 increases during the 2016-2070 period, it remains below the one of other age classes.

[13]The 21st of December 2012 law on the pension reform became effective on the 1st of January 2013. The legal text (*Loi du 21 décembre 2012 portant réforme de l'assurance pension*) can be found at *http://legilux.public.lu/eli/etat/leg/loi/2012/12/21/n7/jo.*

to discourage early retirement/encourage senior labor market participation.

Another measure is activated based on the financial situation of the general scheme and concerns the readjustment mechanism of the revaluation factor, λ. Pensions are currently fully indexed to real wage growth. Every year, the IGSS can recommend limiting pension indexation to real wage growth if pension expenditures of the general scheme exceed pension contributions. In practice, the indexation gradient or moderator (*modérateur de réajustement*), linking pensions to real wage growth, may be revised from 1 to 0.5 or even down to 0, resulting in a weaker increase in λ (see Appendix D for details). A one percent real wage growth would then translate only into a pension growth of 0.5% (or less).

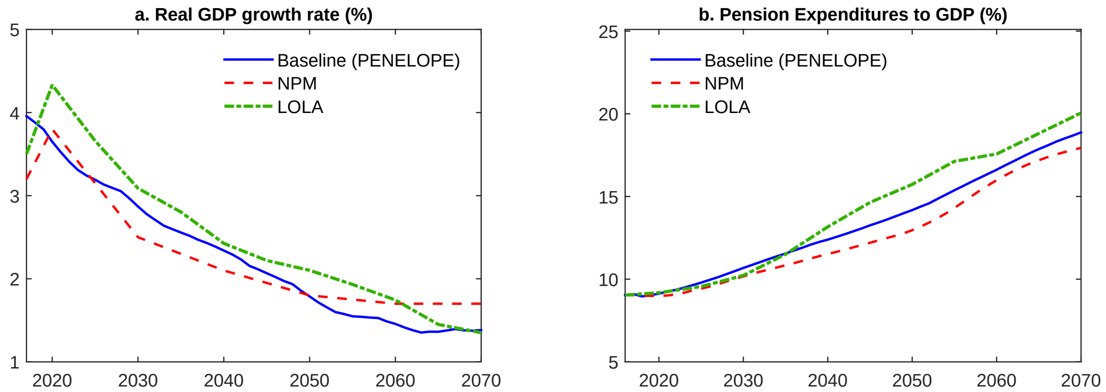
5 Results

This section presents simulations with PENELOPE discussing in turn the findings from (i) a comparison of the baseline results with those of NPM and LOLA, (ii) the effects of alternative demographic assumptions (resident population and cross-border workers), (iii) the implications of the pension reform voted in 2012 and of an alternative reform, the "Plan 50+1" proposed by the Fondation Idea (2018), and finally (iv) a disaggregated analysis focusing on the general scheme.

5.1 Model comparison

Figure 3 illustrates how expected demographics from Eurostat's EP15 projections lead to a rising pension expenditures over the next decades. The three models agree on the rise in pension expenditures to GDP. The pension expenditures to GDP ratio increases between 2016 and 2070 from 9% to 17.9%, 18.9% and 20% with NPM, PENELOPE and LOLA, respectively. Population aging and decreasing cross-border inflows generate weaker growth in the labor force and thus GDP. The increasing number of elderly and lower growth lead to increasing pension expenditures to GDP ratio. The general equilibrium model LOLA differs from the other two models as it features equations resulting from agent optimization and market clearing. Economic growth and pension expenditures are higher in LOLA than in the other two models. One reason is that demographic changes also affect agents' decisions, in particular consumption/savings choices. A standard result in these models is that higher life expectancy stimulates savings for old age (Börsch-Supan et al., 2006). As a consequence, capital accumulation is higher and thus also GDP growth. At the same time, higher wage growth contributes to augment pension expenditures because pensions depend on labor income.

Figure 3: Model comparison: PENELOPE (Baseline), NPM and LOLA

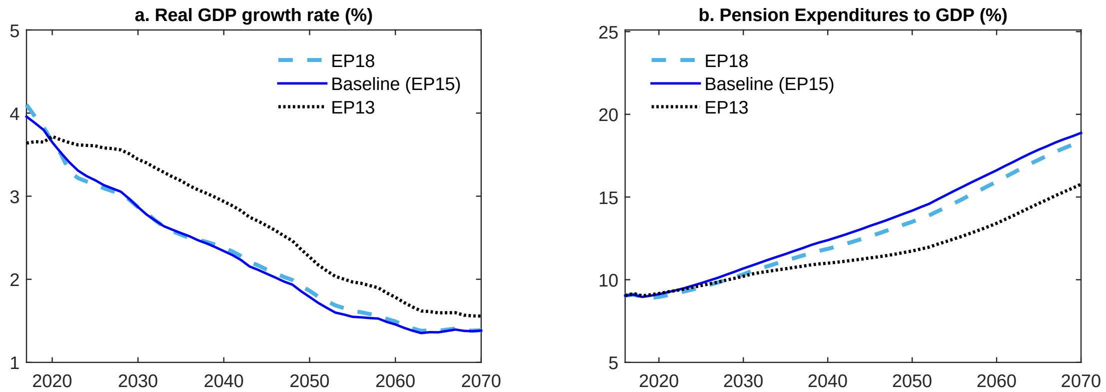


All simulations based on the EP15 vintage of Eurostat's demographic projections. Scenario *Baseline* refers to PENELOPE and results with NPM are those published in the 2018 Ageing Report (EC, 2018). GDP growth rate is a 5-year moving average.

5.2 Demographic assumptions

Figure 4 displays the implications of different evolutions of the resident population. Recall that the population reaches, in 2070, 1.04 and 1.03 million in EP15 and in the EP18 projections, respectively, but 1.22 million in the EP13 projections. It is not surprising that economic growth is larger with the EP13 projections. As a consequence, pension expenditures to GDP in 2070 attain "only" 15.8%, but 18.9% in the EP15 and 18.4% in the EP18 population scenario.

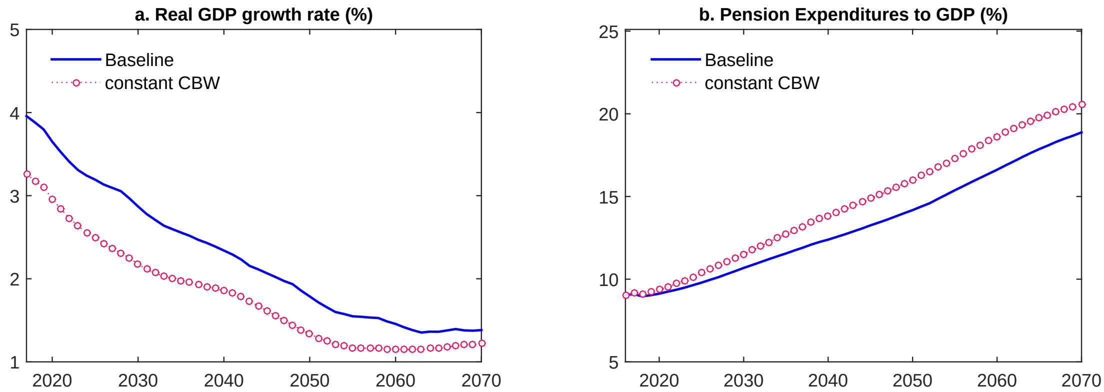
Figure 4: Alternative population projections



Scenarios differ only in the underlying vintages EP18, EP15 and EP13 of Eurostat's population projections. GDP growth rate is a 5-year moving average.

Figure 5 presents the implications of cross-border worker inflows. A lower cross-border inflow scenario, whereby the share of cross-border workers in employment is constant at 40.3%, generates lower activity and GDP growth because it lowers the labor force. As a consequence, pension expenditures to GDP attain 20.5% in 2070 instead of 18.9% in the baseline scenario.

Figure 5: Implications of cross-border inflows



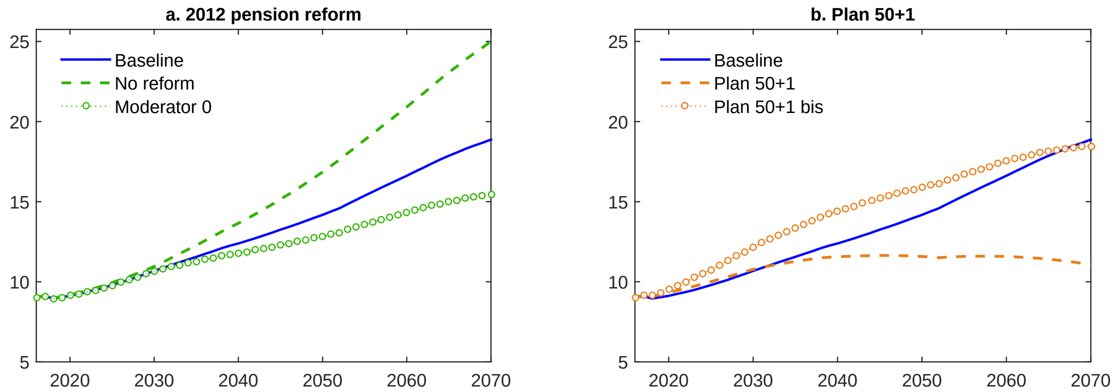
GDP growth rate is a 5-year moving average. *constant CBW* stands for constant cross-border worker share.

5.3 Pension reform scenarios

Figure 6 illustrates the implications of the pension reform voted in 2012 and implemented since January 2013 (panel *a*) as well as those of the Plan 50+1 (panel *b*), which is an alternative reform proposed by the Fondation Idea (2018). The 2012 pension reform affects parameters p_1 to p_3 as well as the dynamics of the pension revaluation factor λ, see equations (4)-(7). Without reform, pension expenditures to GDP would rise from 9% in 2016 to 25% in 2070 (dashed green curve) instead of 18.9% in the baseline scenario, which accounts for the measures of the 2012 reform. It is interesting to see that the difference in pension expenditures between the two scenarios is larger as time passes by, which indicates the progressive nature of the measures of the reform. The baseline comprises also the conditional measure regarding the revaluation factor λ, which is activated after 2027 since pension expenditures exceed pension contributions to the general scheme in 2027. The baseline assumes that pensions are then only linked to 50% to the wage evolution as in Everard (2017) and even completely disconnected from real wage growth in an alternative scenario, *Moderator 0* (green circles). Pension expenditures to GDP increase then only to 15.5% in 2070.

The Fondation Idea (2018) formulated an alternative pension reform that should guarantee the sustainability of the pension system in the long term. Their Plan 50+1 basically consists of a reduction in parameter p_1 linking pensions of work-life income from 1.85% in 2012 to 1% in 2052 (instead of 1.65% with the current reform) and an increase in parameter p_3 from 23.5% in 2012 to 50% in 2052 (instead of 28%). This alternative reform should also reduce pension inequality since it assigns lower weight to the income-related component (P_1) and a greater weight to a non-earning related term (P_3). The Fondation Idea (2018) shows, based on the case study of four typical retirees, that this alternative reform is able to impede the rise in the pension expenditures to GDP provided a constant real GDP growth of 3%. Scenario *Plan*

Figure 6: Pension expenditures under different reforms



Panels *a* and *b* display pension expenditures to GDP (%). *Baseline* incorporates the measures of the 2012 pension reform. *No reform* is a simulation without the measures of the reform and *Moderator 0* with a moderator of 0 instead of 0.5 after 2027. *Plan 50+1* simulates the Fondation Idea (2018) proposal with a 3% constant real GDP growth rate and *Plan 50+1 bis* with a 2% growth rate.

50+1 in panel *b*, implementing the proposal with a real GDP growth constant at 3% (equation (11) is switched off), provides support to the claim since pension expenditures to GDP remain overall stable from 2016 to 2070. Nevertheless, the 3% real GDP growth assumption is quite optimistic since it is above the GDP growth rates prevailing in the baseline scenarios of NPM, LOLA and PENELOPE. It actually turns out to be crucial to maintain stable pension expenditures to GDP as shown in a further scenario *Plan 50+1 bis* implementing the Plan 50+1 under a lower constant GDP growth of 2% over the period 2016-2070 in which pension expenditures to GDP reach 18.5% in 2070.

5.4 Disaggregated analysis: General scheme

The next paragraphs present a disaggregated analysis of the pension system. For comparison purposes, the focus is on the general scheme. In fact, given its mandate to monitor the general regime, the IGSS provides regular reports on the financial situation of this scheme. The general regime is divided into ten-year coverage periods. The contribution rate, i.e. τ in equation (9), is usually determined at the beginning of a coverage period in order to guarantee the ten year sustainability of the system. Actually, the contribution rate can be adjusted every 5 years and a revision of the rate is possible if the scheme's financial situation is endangered. Such a revision is based on the IGSS's mid-period evaluation of the scheme. The current coverage period is 2013-2022 and a mid-term evaluation report has been published in 2016 stating that, at the current contribution rate, pension contributions of the general scheme are sufficient to cover expenditures until the end of the coverage period (IGSS, 2016).

Table 7 reports the evolution of pension expenditures in the general scheme according to

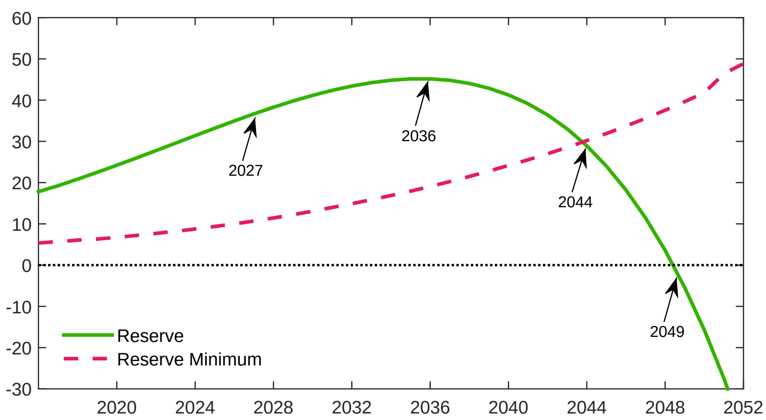
Table 7: Pension expenditures of the general scheme (% of GDP)

Model/scenario	Pop	2016	2035	2055	2060	2070
NPM: mid-term evaluation	EP13	7.1	9.1	11.4	12.4	n.a.
NPM: updated evaluation	EP15	n.a.	n.a.	n.a.	13.8	15.5
PENELOPE: baseline	EP15	7.0	9.1	12.5	13.6	15.6
PENELOPE: constant CBW	EP15	7.0	10.0	13.8	14.9	16.4

Year 2016 corresponds to 2015 in simulation *NPM: mid-term evaluation*, which refers to the results from the IGSS mid-term evaluation based on the EP13 population projections (IGSS, 2016). *NPM: updated evaluation* displays the updated calculations of the mid-term report using the EP15 projections (IGSS, 2018). *PENELOPE: constant CBW* assumes a constant cross-border share in employment. n.a. stands for not available.

different models/scenarios. The IGSS mid-term evaluation, based on the EP13 population projections, indicates that pension expenditures to GDP increase from about 7% in 2016 to more than 12% in 2070 (first row). A more recent analysis, using updated macroeconomic and demographic assumptions based on the EP15 population projections, finds similar expenditures until the middle of the projection horizon but larger costs at the end of the period with pension expenditures to GDP heading at 15.5% in 2070 (row 2). As stated in the report, the reason is that EP13 displays a larger working age population, while the senior population evolves in a similar manner in EP13 and EP15 (see also figure 2). The baseline simulation with PENELOPE arrives at a similar conclusion (row 3). Instead, a scenario based on lower cross-border inflows, and thus weaker GDP growth, leads to pension expenditures to GDP reaching 16.4% in 2070 (row 4).

Figure 7: General scheme reserve (billion euros)



The evolution of the reserve according to PENELOPE's baseline scenario (EP15 population projections and rising cross-border share in employment).

Figure 7 depicts the evolution of the general scheme reserve under the baseline scenario. In 2016, the reserve amounted to 17.8 billion euros, i.e. a reserve to GDP ratio of 33.6%. The reserve rises because of interest income and of a positive balance of the general scheme, see equation (12). The figure highlights four important dates. In 2027, pension expenditures exceed contributions to the general scheme, i.e. $\Gamma_g < 0$ in equation (13). Some of the interest income is used to close the expenditures-contributions gap and the rest of the interest income feeds the reserve. In 2036, the reserve is at its maximum and, after 2036, all the interest income serves to finance pension expenditures. Thereafter, the reserve decreases and in 2044, it falls below the legal minimum threshold of 1.5 times annual pension expenditures. In 2049, the reserve becomes negative.

Table 8: Key dates in the evolution of the reserve in various models/scenarios

	$\Gamma_g < 0$	$R_g < R_g^{min}$	$R_g < 0$
NPM: mid-term evaluation	2023	2035	2043
NPM: updated evaluation	2024	2035	2041
NPM: AR2018 contribution	n.a.	2042	2047
PENELOPE: baseline	2027	2044	2049
PENELOPE: EP18	2028	2048	2052
PENELOPE: constant CBW	2024	2040	2044
PENELOPE: constant CBW & i=3%	2024	2036	2040

The simulation *NPM: mid-term evaluation* refers to the IGSS mid-term evaluation (IGSS, 2016), *NPM: updated evaluation* to the updated evaluation (IGSS, 2018) and *NPM: AR2018 contribution* is the IGSS's contribution to the 2018 Ageing Report (Everard, 2017). Scenario *PENELOPE: baseline* is PENELOPE's baseline scenario, while *PENELOPE: EP18* are based on the EUROPOP2018 projections, *PENELOPE: constant CBW* assume a constant share of cross-border workers in employment and *PENELOPE: constant CBW & i=3%* also considers a nominal return on the reserve of 3% instead of 5%. The second column refers to the year where the general scheme balance Γ_g turns negative i.e. pension expenditures exceed contributions. The third column indicates when the reserve of the general scheme R_g falls below the legal minimum reserve threshold R_g^{min} of 1.5 times annual pension expenditures. The last column reports the year when R_g is exhausted. n.a. stands for not available.

It is worth comparing these key dates in the evolution of the reserve with those of other analyzes. Table 8 presents results from alternative scenarios with PENELOPE and from other studies. The *NPM: mid-term evaluation* simulation (row 1) refers to the IGSS report on the mid-term evaluation of the general scheme and indicates that the general scheme turns into deficit ($\Gamma_g < 0$) in 2023 and thus interest income from the reserve do not serve to feed only the reserve but must also finance pension expenditures. The reserve falls below the minimum threshold in 2035 and becomes negative in 2043. The updated report, outlined by the *NPM:*

updated evaluation simulation (row 2), relies on the less favorable EP15 population projections of the 2018 Ageing Report and finds that the reserve turns negative already in 2041. Both simulations assume a 1% real return on the reserve. The *NPM: AR2018 contribution* simulation (row 3) is based on the EP15 population projections and assumes a 5% nominal return on the reserve. The reserve falls below the legal minimum in 2042 and becomes negative in 2047. In PENELOPE's baseline simulation (row 4), based on the EP15 population projections and a rising cross-border employment share, the reserve turns negative only in 2049. The scenario with lower cross-border worker inflows is closer to the simulations with NPM and implies a negative reserve in 2044. Finally, assuming weaker cross-border inflows and a lower return on the reserve leads to key dates that are close to the *NPM: updated evaluation* simulation.

6 Conclusion

PENELOPE is a macro-accounting tool aimed at examining the long-run sustainability of the Luxembourg pension system. It complements existing models like the macro-accounting National Pension Model (NPM) and the general equilibrium model LOLA. Like LOLA, it is an integrated approach calculating the direct and indirect effects - through labor supply and economic growth - of demographic changes on pension expenditures and contributions, while the evolution of macroeconomic variables is evaluated by external tools in NPM. Moreover, like NPM but unlike LOLA, PENELOPE allows for a disaggregated pension analysis distinguishing between the pension schemes and the various types of beneficiaries and contributors. For instance, beneficiaries differ by their residence and retirement age but also by the pension scheme they belong to and by the type of pension they receive. PENELOPE is a compromise between NPM and LOLA, being less detailed on the pension side than NPM and less rich on the macroeconomic side than LOLA.

The baseline results of PENELOPE indicate that pension expenditures to GDP rise from 9% in 2016 to 18.9% in 2070. This parallels the findings of NPM and LOLA with pension expenditures to GDP climbing at 17.9% and 20%, respectively, in 2070. Further exercises display the effects of population projections and cross-border worker inflows, the implications of the 2012 pension reform and of the Plan 50+1 proposal of the Fondation Idea (2018) as well as the dynamics of the pension reserve.

The PENELOPE tool can be improved in many ways. For instance, the calibration can be refined using more detailed data on beneficiaries and contributors. Moreover, the macroeconomic relations can be revisited like related to the labor market. Further effort could also spent on incorporating additional public expenditures. Finally, future work could focus on exploring scenarios that keep public finance sustainable over the longer term.

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Appendix

Appendix A provides further information to the Ageing Report and Appendix B to the calculation of beneficiary groups. Appendix C explains the calculation of the GDP growth rate and Appendix D describes the revaluation and readjustment mechanisms. Finally, Appendix E and Appendix F give details on the evolution of cross-border beneficiaries and labor market participation, respectively.

A Introduction: Ageing working Group

The Ageing Report is jointly prepared by the European Commission's Directorate-General for Economic and Financial Affairs (DG-ECFIN) and the Economic Policy Committee's Ageing Working Group (AWG). The report, published every three years, is divided into two volumes issued at a six-month interval. The first volume contains the evolution of the exogenous demographic and macroeconomic variables. These are necessary for the calculations of long-term budgetary costs, which are published in the second volume. Note that the first volume of *2018 Ageing Report* was published in November 2017 (EC, 2017) and the second volume in May 2018 (EC, 2018). Demographic and macroeconomic variables are derived from common assumptions and methodologies for all Member States (upon agreement by AWG experts), while budgetary costs are calculated separately by each Member State. Broadly speaking, assumptions on the demographic evolution as well as on other factors (e.g. productivity) are used in the various DG-ECFIN modules computing specific variables (e.g. age-specific labor force participation rates), which lead in fine to aggregate indicators such as GDP. Note that Eurostat's population projections also originate from a collaboration between Eurostat and the national statistical institutes of EU Member States.

B Model: Beneficiary groups

This section explains the calculation of the evolution of pension recipients. As mentioned in section 3, B_{hijk} represents the number of beneficiaries classified into category $hijk$, where subscript h stands for the pension scheme they belong to, subscript i indicates the type of pension they receive, subscript j informs on the residence of recipients (i.e. the location to which the pension is paid) and subscript k indicates whether the pension is anticipated or obtained at legal age. The discussion below focuses on beneficiaries of the general scheme (subscript h=g) obtaining an old-age pension (subscript i=o). It explains the calculation differences between resident, emigrated and cross-border beneficiaries (subscript j=r, e, f) and recipients of legal age and anticipated pensions (subscript k=l, a). Figure 1 in section 3 illustrates how recipients form the general scheme are split up. The calculation of the dynamics of other beneficiary groups is briefly addressed at the end of this section.

Resident and emigrated beneficiaries. The dynamics of the number of resident beneficiaries of the general scheme obtaining an old-age pension at legal age, B_{gorl}, is described by

$$B_{gorl,t} = \frac{(1-\rho_{r,t}^{65+})\, Z_{r,t}^{65+}}{(1-\rho_{r,t-1}^{65+})\, Z_{r,t-1}^{65+}}\, B_{gorl,t-1} \tag{14}$$

where Z_r^{65+} is the resident population aged 65+ and $\rho_r^{65+} \in [0,1]$ is the share of Z_r^{65+} entitled to a public sector pension (thus, $1-\rho_r^{65+}$, is the private sector share). Equation (14) states that B_{gorl} evolves proportionally to the resident population aged 65+ having retired from the private sector. B_{gorl} depends on $\rho_{r,t}^{65+}$ and $Z_{r,t}^{65+}$, where the former is constant and the latter's evolution is given by Eurostat's demographic projections (labor market participation effects are ignored for this age group). Recall that the initial values for the variables B_{gorl}, Z_r^{65+} and ρ_r^{65+} are computed from the data (see section 4).

Similarly, the number of resident individuals receiving an anticipated old-age pension from the general scheme, B_{gora}, is given by

$$B_{gora,t} = \frac{(1-\ell_{r,t}^{5564})(1-\rho_{r,t}^{5564})Z_{r,t}^{5564}}{(1-\ell_{r,t-1}^{5564})(1-\rho_{r,t-1}^{5564})Z_{r,t-1}^{5564}}\, B_{gora,t-1} \tag{15}$$

where ℓ_r^{5564} is the labor market participation rate of the resident population aged 55 to 64, Z_r^{5564}. Equation (15) indicates that B_{gora} evolves according to the resident non-active "private sector" population belonging to the 55-64 age class.

It is further assumed that the number of emigrated beneficiaries (subscript *j=e*), i.e. individuals in non-neighboring countries entitled to Luxembourg pensions, evolves like the number of their resident peers, e.g. $B_{goel,t} = B_{gorl,t}/B_{gorl,t-1} \cdot B_{goel,t-1}$.

The computation of other resident and emigrated recipient groups is similar (see further below), so that it is possible to obtain the total number of resident and emigrated beneficiaries (B_r and B_e).

Cross-border beneficiaries. Cross-border beneficiaries (subscript *j=f*) are defined as individuals living in neighboring countries and entitled to a Luxembourg pension. B_r, B_e and B_f represent the total number of resident, emigrated and cross-border beneficiaries, respectively and γ_B is the share of cross-border retirees among all beneficiaries. More precisely, $B_{f,t} = \gamma_{B,t}(B_{r,t} + B_{e,t} + B_{f,t})$, which gives equation (2) in section 3. Thus knowing B_r and B_e from above and taken γ_B as given by the rule described in Appendix E, it is possible to compute the total number of cross-border recipients B_f. The cross-border recipients are next classified into cross-border beneficiaries of anticipated pensions, B_{fa}, and of pensions received at legal age, B_{fl}.

The following steps allow deriving B_{fa}. The number of cross-border workers aged 55-64 is determined by

$$N_{f,t}^{5564} = \gamma_{N,t}(N_{r,t}^{5564} + N_{f,t}^{5564})$$

where N_r^{5564} represent the number of resident workers aged 55 to 64 and it is assumed that the proportion of cross-border workers among workers aged 55-64 is identical to the proportion of cross-border workers in total employment γ_N. Moreover, define

$$Z_{f,t}^{5564} = N_{f,t}^{5564} + \ell_{f,t}^{5564} Z_{f,t}^{5564}$$

where ℓ_f^{5564} is the labor market participation rate of potential cross-border beneficiaries aged 55-64, Z_f^{5564}. The number of potential cross-border recipients aged 55-64, Z_f^{5564}, is defined as the sum of individuals aged 55-64 and living in neighboring countries and working in Luxembourg, N_f^{5564}, and of individuals having worked in Luxembourg, who are represented by the second term on the right-hand-side (note that unemployed individuals aged 55-64 are not distinguished in this definition). Assume that the labor market participation rate of potential cross-border beneficiaries equals the resident one, i.e. $\ell_f^{5564} = \ell_r^{5564}$. Combining the above two equations allows deriving Z_f^{5564} as follows

$$Z_{f,t}^{5564} = \frac{N_{r,t}^{5564}}{\ell_{r,t}^{5564}} \frac{\gamma_{N,t}}{1 - \gamma_{N,t}} \tag{16}$$

Lastly, the number of cross-border beneficiaries entitled to any type of anticipated pension, B_{fa}, is obtained from

$$B_{fa,t} = b_{fa,t}\,(1 - \ell_{r,t}^{5564})\, Z_{f,t}^{5564} \tag{17}$$

where $b_{fa} \in [0, 1]$ is the fraction on non-active potential cross-border beneficiaries aged 55-64 entitled to an anticipated pension. Equation (17) indicates that some of the non-participating cross-border individuals, $(1 - \ell_r^{5564}) Z_f^{5564}$ are cross-border beneficiaries of anticipated pensions. The dynamics of b_{fa}, which is the fraction on non-active potential cross-border beneficiaries aged 55-64 entitled to an anticipated pension, is described by

$$b_{fa,t} = \frac{\gamma_{B,t}}{\gamma_{B,t-1}}\, b_{fa,t-1} \tag{18}$$

meaning that b_{fa} is driven by γ_B. Using equation (18) in equation (17) leads to function $\mathcal{F}$ appearing in equation (3), with B_{fa} depending on γ_B and Z_f^{5564}. It is now straightforward to obtain the cross-border recipients of pensions at legal age $B_{fl,t} = B_{f,t} - B_{fa,t}$. Note that, at time 0, b_{fa} is used to match the initial number of B_{fa} calculated from the data (time t=0 is year 2016 in the present calibration). Indeed, the initial value of b_{fa} is derived by combining equations (16), (18) and (17), given the initial values for B_{fa}, ℓ_r^{5564}, N_r^{5564} and γ_N

$$b_{fa,0} = \frac{B_{fa,0}}{N_{r,0}^{5564}} \frac{\ell_{r,0}^{5564}}{1 - \ell_{r,0}^{5564}} \frac{1 - \gamma_{N,0}}{\gamma_{N,0}}$$

More specific cross-border beneficiary groups are derived as follows. The proportion of cross-border beneficiaries entitled to a special scheme pension, $\rho^{5564}_{f,t}$, allows splitting $B_{fa,t}$ into special and general scheme beneficiaries. Cross-border general scheme beneficiaries of anticipated pensions is given by $B_{gfa,t} = (1 - \rho^{5564}_{f,t})B_{fa,t}$. The dynamics of the number of cross-border beneficiaries entitled to an anticipated old-age pension from the general scheme, B_{gofa}, is obtained from

$$B_{gofa,t} = \frac{B_{gfa,t}}{B_{gfa,t-1}}\, B_{gofa,t-1} \tag{19}$$

Equation (19) is the equivalent of equation (15) and indicates that $B_{gofa,t}$ evolves according to $B_{gfa,t}$. The dynamics of cross-border beneficiaries entitled to an old-age pension at legal age from the general scheme, B_{gofl}, is described by

$$B_{gofl,t} = \frac{B_{gfl,t}}{B_{gfl,t-1}}\, B_{gofl,t-1} \tag{20}$$

with $B_{gfl,t}$ being the number of cross-border beneficiaries from the general scheme entitled to pensions at legal age, i.e. $B_{gfl,t} = (1 - \rho^{65+}_{f})B_{fl,t}$ where $\rho^{65+}_{f,t}$ is the proportion of cross-border beneficiaries aged 65+ entitled to a special scheme pension. The same procedure is applied to calculate other cross-border beneficiary groups of legal age and anticipated pensions.

Other beneficiaries. Finally, other recipients, like those belonging to the special schemes or those entitled to disability and survival pensions are computed in a similar way than above. For instance, B_{sorl} and B_{sora}, i.e. the number of resident individuals benefiting from legal age and anticipated special scheme (subscript *h*=*s*) pensions, are calculated simply by replacing the factor $1 - \rho$ by ρ in equations (14) and (15). Note that no retirement age distinction is made for survival pensions of orphans (subscript *i*=*v*) and disability pensions are considered as old-age pensions when recipients have reached 65 years.

C Model: Output growth rate

Consider a standard Cobb-Douglas production function: $Y_t = A_t K_t^{\alpha} {N_t}^{1-\alpha}$, with Y representing output, A productivity, K capital, N employment and α the capital share in production. Taking logs of $Y_t = A_t K_t^{\alpha} {N_t}^{1-\alpha}$ yields

$$\Leftrightarrow\; log(Y_t) = log(A_t) + \alpha\, log(K_t/N_t) + log(N_t)$$

First-differencing and assuming a constant capital-labor ratio implies

$$\Leftrightarrow\; log(Y_t/Y_{t-1}) = log(A_t/A_{t-1}) + log(N_t/N_{t-1})$$

Defining $g_{\Psi,t} \equiv \Psi_t/\Psi_{t-1} - 1$ the annual growth rate of variable Ψ from $t-1$ to t gives

$$\Leftrightarrow\; log(1 + g_{Y,t}) = log(1 + g_{A,t}) + log(1 + g_{N,t})$$

Finally, using a first-order Taylor series approximation leads to equation (11)

$$\approx \; g_{Y,t} = g_{A,t} + g_{N,t}$$

D Model: Cost of living, pension revaluation and moderator

Cost of living index and pension revaluation factor

The work-life income, $LifeInc$, and the social minimum income, $MinInc$, appearing in equations (5) to (8) are expressed in past price and real wage levels and factors ϕ and λ ensure the updating of pensions at current levels. The first pension received by a newly retired person is multiplied by ϕ and by λ to account for the price evolution since 1948 and the real wage evolution since 1984, respectively. By law, ϕ equals the *current* cost of living index as computed by Statec, while λ is set to the fourth year preceding entitlement value of η, which is the revaluation factor for salaries and wages (*facteur de revalorisation applicable aux salaires, traitements ou revenus cotisables*). This means, for instance, that individuals entitled to a first pension in January 2016 obtain a pension based on $\phi = 7.7517$, which is the cost of living index having prevailed at that moment, while λ is based on the revaluation factor for salaries and wages of 2012 i.e. $\eta_{2012} = 1.42$. The following pensions may evolve with changes in ϕ and λ representing the on-going price and real wage evolutions. For instance, ϕ is raised each time the price level increases by more than 2.5%. Multiplying the first pension by ϕ and λ is referred to as the pension revaluation (*revalorisation*), while the changes in ϕ and λ affecting the following pensions represent the readjustment mechanism (*mécanisme de réajustement*).

In PENELOPE, beneficiary groups are composed of individuals having retired at different dates and there is a unique λ representing an average over individuals having retired at different dates. More precisely, the initial λ is computed for year t=0 i.e. year 2016 in the present calibration (see section 4). The pension revaluation factor in year $t > 0$

$$\lambda_t = (1 + m_{t-2}\; g_{\eta,t-2})\, \lambda_{t-1} \tag{21}$$

where $g_{\eta,t-2}$ is the growth rate of the wage revaluation factor between year $t-2$ and year $t-3$ and $m \in [0,1]$ is an indexation gradient or moderator (*modérateur de réajustement*). The growth of η equals real wage growth (g_A) and the setting of the moderator is explained further below.

It is useful to briefly expose how λ is generally set. Denote by λ_t^a the pension revaluation factor in year t of a retiree having obtained her/his first pension in year a. In year t=a, λ^a is described by $\lambda_t^a = \eta_{a-4}$ and in successive years, i.e. t>a, by $\lambda_t^a = (1 + m_{t-2}\; g_{\eta,t-2})\, \lambda_{t-1}^a$. This means that the initial pension, received in year t=a, is characterized by a pension revaluation factor corresponding to the wage revaluation factor of the fourth year preceding the pension entitlement. After year a, the moderator m and the growth of η influence the pension revaluation factor.

Moderator

The 2012 pension reform establishes the mechanism setting the value of the moderator. The moderator, m, currently equal to 1, can be lowered each year to 0.5 or less in case pension expenditures of the general scheme exceed contributions. More precisely, every year t (the year of the revision), the IGSS publishes pension contributions and expenditures of year $t-2$ and recommends, if the latter exceed the former, a decrease in the moderator of the next year(s) to dampen the evolution of the revaluation factor. According to the legal text (see further below) and formulation in equation (21), this implies that the moderators starting from the year preceding the revision, i.e. $\{m_{t-1}, m_t, ...\}$, are decreased, which affects the revaluation factors $\{\lambda_{t+1}, \lambda_{t+2}, ...\}$. This two year delay in the triggering of this measure works as follows in the baseline simulation of section 5. The general scheme is found to enter into deficit in 2027, which changes the moderator of 2027 that applies to the revaluation factor of 2029 (thus pension expenditures are affected only starting from 2029 onwards). Note that the moderator can be set back to 1 if contributions of the general scheme start covering again expenditures (but, as in Everard (2017), this possibility is not considered in the present simulations).

According to the legal text (IGSS, 2019, p.151): *Les pensions calculées conformément à l'article 225 sont multipliées par le produit des différents facteurs de réajustement déterminés par année de calendrier et ce à partir de l'année postérieure au début du droit à la pension, mais au plus tôt à partir de l'année 2014. Le facteur de réajustement représente pour une année de calendrier la somme de l'unité et du produit de la multiplication du taux de variation annuel du facteur de revalorisation entre l'avant-dernière année et l'année précédant celle-ci par le modérateur de réajustement applicable pour l'avant-dernière année. Ce modérateur de réajustement est fixé à 1 à partir de l'année 2012. Tous les ans, le Gouvernement examine s'il y a lieu de procéder ou non à la révision du modérateur de réajustement par la voie législative. Si la prime de répartition pure de l'avant-dernière année précédant celle de la révision dépasse le taux de cotisation global visé à l'article 238, le Gouvernement soumet à la Chambre des Députés un rapport accompagné, le cas échéant, d'un projet de loi portant refixation du modérateur de réajustement à une valeur inférieure ou égale à 0,5 pour les années à partir de l'année précédant la révision. Toutefois, le modérateur de réajustement peut de nouveau être augmenté à une valeur ne dépassant pas 1 pour les années à partir de l'année précédant la révision, si le taux de cotisation global visé à l'article 238 pour l'avant-dernière année précédant celle de la révision dépasse la prime de répartition pure.*

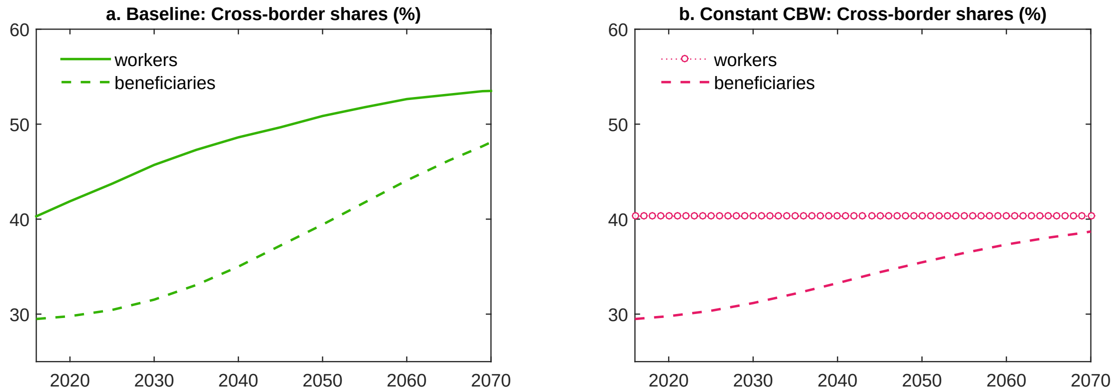
E Calibration: Share of cross-border beneficiaries

The share of cross-border retirees among all beneficiaries, γ_B, evolves according to

$$\gamma_{B,t} = \gamma_{B,t-1} + \delta_t \cdot \sigma \cdot \max(0, \gamma_{N,t-1} - \gamma_{B,t-1}) \qquad (22)$$

where γ_N is the cross-border worker share and $\sigma \in [0,1]$ determines the catch-up of γ_B on γ_N and $\delta \in [0,1]$ describes the path of γ_B. In particular, the values for δ are set such that γ_B progressively approaches γ_N (but never exceeds it), while σ is calibrated to 0.272 such that the initial gap between γ_N and γ_B in 2016 is reduced by half in 2070, as explained in section 4.2. The values for σ and the sequence of δ's are kept unchanged in all scenarios, implying a rising γ_B also in the alternative scenario in which γ_N is assumed constant, see Figure 8.

Figure 8: Cross-border individuals among workers (γ_N) and pension beneficiaries (γ_B)



The baseline scenario (left) assumes a rising cross-border worker share, γ_N, and scenario *constant CBW* (right) a constant γ_N. Equation (22) governs the cross-border beneficiary share, γ_B, in both cases.

F Calibration: Work-life income

In fact, work-life income $LifeInc$ should be constant if it is affected only by wage indexation (inflation) and real wage growth (productivity), since these factors are accounted for by changes in ϕ and λ. However, other elements may affect $LifeInc$. For instance, the study by the Fondation Idea (2018) assumes a trend in individual salaries, supposed to capture seniority and promotions. In the present study, work-life income, $LifeInc$, increases in accordance with the rising senior labor participation explained in section 4. A mild yearly increase in $LifeInc$ of around 0.5% between 2016 and 2070 is considered (this is about the annual growth rate of the calibrated $LifeInc$ in the general scheme since the 2012 reform). Indeed, higher senior participation means longer careers and thus more contributory revenues (and years), which augment work-life income $LifeInc$. Moreover, these additional revenues are earned at final stages of the career, and usually exceed average income, meaning that higher senior participation results in $LifeInc$ being composed of more and more above-career average salaries.

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