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Asset Liability Management: Evidence from the Banco de Portugal defined benefit pension fund

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Abstract

The level of financing of pension funds and the inherent risk of default is an issue which has assumed increasing relevance, due to the difficulties that pension funds have been facing over recent years, which mainly result from changes in demographic conditions, such as the ageing of the population and increasing longevity, compounded by the 2008 financial crisis and the Great Recession. Asset Liability Management (ALM) models can be employed to optimise assets and liabilities, and at the same time minimise the risks of a fund, whereby the choice of the best model for a fund depends on the fund's specific characteristics and risk-return profile. This paper is mainly a theoretical study, where a literature review is first carried out both on pension plans and pension funds and also on the importance of ALM. This is followed by an analysis of the evolution of this risk management instrument and a description of the selected models is then presented. To conclude, an analysis of the application of ALM for a pension fund, the Banco de Portugal defined benefit pension fund, is carried out.

Keywords: Pension Funds, Pension Plans, Asset Liability Management, Risk Management, Funding Ratio

1. Introduction

Pension funds have an important role to play in the economy, as they are one of the largest institutional investors. At the end of 2017, the value of the assets of private pension funds in Portugal had attained 19,700 million euros[1], which represented 10.2% of gross domestic product (GDP).

Over the last years, demographic problems, increasing longevity, the decline of fertility, poor stock markets' returns, and falling interest rates have all jeopardised the financial position of private pension schemes, putting them under pressure. Consequently, there has a been a significant shift from defined benefit (DB) pension plans to defined contribution (DC) pension plans throughout most of the OECD countries (OECD, 2005; Broadbent et al., 2006; Turner and Hughes, 2008). This transition will bring higher risks to employees due to the specific attributes of the two types of plans which are significantly different (Davis, 1995) as under a DC plan the employee bears all of the investment risk and the firm has no obligation beyond making its periodic contribution. In fact, valuation of the DC plans is somehow straightforward because it simply measures the market value of the assets held in the retirement account, although the actual size of the retirement annuity will, of course, depend upon the realized investment performance of the pension fund, the interest rate at retirement, and the ultimate wage path of the employee. On the other hand, DB plans focus on the flow of benefits which the individual will receive upon retirement and is determined by a formula which takes into account wages or salary, years of service for the employer and, in some cases, other factors. Hence, the calculation of the funding status of DB plans is much more complex. If the plan's assets are invested in traded securities, their market value is relatively easy to ascertain whilst

[1] https://www.asf.com.pt/ISP/Estatisticas/fundos/estatisticas_anuais/historico/Montantes%20geridos%20(2017).pdf

the source of difficulty is in measuring the sponsor's liability. Indeed, from a strictly legal point of view the sponsor's liability is the present value of the accrued vested benefits which would be payable if the plan was immediately terminated. However, some pension experts contend that sponsors have an implicit semi contractual obligation which makes it more appropriate to take account of projected future salary growth in the computation of the firm's pension liability, making it unclear whether a real or nominal interest rate should be used in discounting future benefits (either with or without salary growth projections) to compute the present value. In summary, DB pension plans require actuarial valuations, which is an aspect of costs not required for DC plans. Hence, the decreasing trend of the DB plans type, and the increasing trend of the DC plans type is probably the result of the accounting rules and regulatory changes (Yermo, 2007).

The major advantage of DB plans is the potential they offer to provide a stable replacement rate of final income to workers, although the protection offered to workers is risk borne by the firm. However, employers also have reasons for wanting to provide DB pension plans namely to enforce a long-term implicit contract with employees that can importantly affect productivity (influencing the type of worker attracted to the job and shaping behavior while on the job) and retirement decisions (Ippolito, 1997).

When considering the size of pension funds and the associated risks that need to be managed, there is an increasing concern for the development of new approaches to manage the risks and maximise returns – which are also known as Asset Liability Management (ALM) models.

For most of the time, decisions related to the management of a pension fund and the definition of strategies and policies are based on ALM models. Depending on the objectives, several kinds of models exist, all of which that have gone through an evolution process.

Accordingly, the right model for a pension fund depends on its specific characteristics and the complexity of the problem.

In this paper, we first carry out a review of the relevant literature on pension funds and Asset Liability Management and examine why this risk management approach is so important for the financial position of a pension fund. Next, the evolution of ALM models over the years is presented and the selected models are described. To conclude, an analysis of the Banco de Portugal (BdP) defined benefit pension fund is carried out, using the principles of ALM.

2. Pension Funds

Pension systems may have three pillars, guaranteeing that a citizen is able to receive enough income to maintain the same standard of lifestyle after retirement. The first pillar is the obligatory public pension, the second is the adoption of voluntary occupational pension plans – which are usually the responsibility of employers. The last pillar is personal savings – comprised of the savings which individuals make while continuing to work up until retirement time (Garcia, 2013). In Portugal, the public system is the substantial longstanding pillar (Garcia, 2017).

The focus of this paper is private occupational pension funds – where some important concepts need to be addressed. As a definition, a pension fund is a fund which pools the contributions paid in from pension plans set up by employers, unions, or other organisations, whose objective is to control and to manage the assets with the objective to provide retirement benefits. A pension plan is a scheme that establishes the rules for access early or age retirement pensions and disability or death benefits – where the benefits can be a lump sum, an annuity, or a mixture of the two. The sponsor is a legal entity, whose pension plans are funded through a pension fund, which, in turn, is managed by a specialised institution, which can be a pension fund management company or a life insurance company (Garcia, 2014a, 2014b).

Regarding the classification of a pension fund, these are called a public pension fund when regulated by public sector law and the government is responsible for guaranteeing the payment of the benefits. At the opposite end of the spectrum, the term private pension fund is used if the fund is regulated by the private sector law and the private sponsors are responsible for guaranteeing the payment of the benefits.

A pension fund is considered to be a closed pension fund when it has only one sponsor, or if should there be more than one, these are all part of a business association, or have a professional or social connection. A pension fund is open when the sponsors have no direct relationship and the decision to include new sponsors only depends on the company that is managing the fund.

Private pension plans can be classified as a ‘defined benefit plan’ or as a ‘defined contribution plan’. The main differences between them are that the defined benefit plan is independent of the contributions and of financial conditions, and the benefits are set in advance, with the plan sponsor bearing the investment risk. In the cases of the defined contribution plan, the benefits remain uncertain, depending on the development of the investments’ value and contributions. In the Appendix, Figure A.1 presents the percentage of pension’s assets by type of pension plan and the differences across countries. From among the countries selected, Portugal is one of the ones with the highest percentage of pension’s assets financing defined benefit plans (71.3% in 2016). For several years, most pension plans were defined benefit plans, but nowadays, with the difficulties encountered by sponsors in assuring the payment of the benefits, a transformation has taken place, with most plans now becoming defined contribution plans. Sweeting (2007) surveyed FTSE100 companies and concluded that the type of pension plan gives important information about a company, with differences across industries, e.g., Information Technology firms are more likely to have a defined contribution plan.

A pension plan can be classified as ‘contributive plan’ if it is financed by both the employee and employer, and ‘non-contributive’ if there is no sharing of financing responsibilities and the employer is solely responsible for paying in the contributions.

For a company, some of the advantages of having a pension plan include an increase in productivity and well-being of the staff, where the turnover of the oldest employees is facilitated by assuring that they can afford to retire. A pension plan also improves competition for employees and is a way of retaining and attracting the best ones. Additional reasons for having a pension plan can include pressure exerted by trade unions and employee work commissions, tax incentives when compared with other remunerations, and it can also be considered to be a part of the company's social responsibility. While for the workers, in the face of the uncertainty of State-sponsored social security systems, having an income on retirement from the private sector is a way of assuring an income during retirement. In conclusion, the design of a plan is derived from the weight given by the sponsor to each of these above-mentioned motivations.

Sources of risk for a pension fund include actuarial risk, longevity risk, the risk of default, and the indexation of the value of the pension funds. The indexing of benefit payments is in effect the increasing of nominal benefit payments in line with inflation, in order to assure that the purchasing power of retired people is not negatively affected by increases in prices and wages. Fluctuations in currency, volatility, the default of the assets, and uncertainty of the financial markets' development represent other major sources of risk that need to be managed (Drijver, 2005).

Mainly due to increasing life expectancy and population ageing, one of the actions that mostly OECD countries are adopting is the increase of the statutory pension age. At the beginning of 2018, the pension age in Portugal for the social security system increased to 66 years and 4 months. Figure A.2 in the Appendix shows the legal retirement age for all the European countries in 2018.

Figure A.3, which is also presented in the Appendix, shows pension funds' assets as a % of GDP for the 17 countries of the Euro Area in 2016, and from these values it is possible to assess the importance of these funds in their respective economies. In the specific case of Portugal, the value of pension funds' assets is about 10% of GDP, and it is worthwhile to highlight the case of The Netherlands (180%), followed by Finland (51%), and Malta and Ireland (both with 39%).

The financial distress that has confronted some pension funds during this century has increased the importance of regulation in this area, especially of regulatory minimum funding requirements. In the case of Portugal, the regulatory entity for pension funds is *Autoridade de Supervisão de Seguros e Fundos de Pensões* (Portuguese Insurance and Pension Funds Supervisory Authority) (ASF). For the BdP defined benefit pension fund, the BdP pension funds management society defines, additionally, certain, more restrictive, internal regulations. For example, at the end of 2017, the funding policy established by ASF targets the minimum solvency ratio of funding level, in Portugal, at 53.2 percent while the minimum mandatory funding ratio considered by BdP pension fund management society was 98.1 percent[2] (Banco de Portugal, 2017). The funding ratio is a key concept for the solvability of a pension fund, which can be defined as being the portion of the actuarial liability that is funded by the fund's value.

3. ALM for pension funds

Asset Liability Management (ALM) is a risk management approach which considers the assets, liabilities and supervisory regulations in force in the exercise of matching assets and liabilities, with the objective to assure the maintenance of a certain level of solvency for the fund over time. The 20th century demographic context, together with the financial crisis of the recent past have contributed to the increasing importance of ALM techniques in the economy (Toukourou and Dufresne, 2015).

[2] Aviso do BdP nº12/2001.

Looking at Figure A.4 in the Appendix, the dimension of the ageing of the population is observable. For example, in Portugal the old-age dependency ratio was 19.6% in 1975, 34.6% in 2015, and in 2050 it's expected to be 73.2% – which means that in the space of 35 years the number of people older than 65 years per 100 people of working age (20-64) will more than duplicate. This trend is present not only in Portugal, but also in the other countries, and gives rise to the need to anticipate the challenges that pension systems will come to face and the need for efficient risk management tools.

ALM models are an essential instrument for a pension fund to meet its obligations and assure a certain funding ratio that has a minimum value defined by the supervisory entity. Inefficient modelling, or even the absence of modelling of the ALM in some cases, can be the explanation for the pension funding crisis (Berardinelli et al., 2007).

ALM management should follow certain principles, principally to identify the risks and the potential impact in the fund value and to learn how to manage them efficiently, centred on the use of a set of a well-defined set of procedures and the assurance that the investment structure is adjusted to the risks. ALM decisions must take into consideration not only the different objectives, but also the restrictions imposed by the supervisory entity. Another important point is that a fund that aims to maximise returns without giving special attention to the potential loss will have a different ALM model than one that primarily has as its objective the neutralization of losses. Therefore, each case is a different case and a careful evaluation of the objectives, restrictions, and conditions should be completed to find the fit of the right ALM model and to be able to select the most suitable investment portfolio, whilst bearing in mind the risk-return maximisation (Boender, Dert, Heemskerr and Hoek, 2007).

The results of the decisions made by the board of a pension fund directly affect the different parties involved. For instance, in a contributive fund, when active participants exist and are worried about changes in the contribution rate, and some of these participants are nearing retirement age, they will also have an interest in the level of indexation of the pension. Retirees and surviving relatives are mainly affected by the indexation level of the benefits that they receive, which can impact their ability to face the inflation changes over the years. Another important factor is the sponsor that pays contributions, as it is a party that has a higher sensitivity to the financial progression of the fund and assumes some of the risks. For example, if the funding ratio is below a certain level, the sponsor may then have to restore the value through extraordinary contributions. However, it is also important to refer that the sponsor can also benefit if the fund is prospering. The sponsor is also interested in the administrative costs. Finally, there is the supervisory entity, to whom the pension fund board members must report and justify their decisions. It can be difficult to conciliate the interests of all these parties, in that a decision that satisfies one party, can represent a conflict of interest with another party, and this can render ALM a challenging process (Cannas, 2010).

Two other important concepts are the solvency of the pension fund – which is the ability of a pension fund to assure all the payments in the long-run at a certain moment it is valued – and the funding ratio – which is the amount of assets divided by liabilities. The latter must be guaranteed, with a large probability that the solvency restrictions are accomplished and that the returns are maximised. Consequently, a concern of the board of a fund is the risk of underfunding – when the value of the liabilities is higher than the value of the assets. As can be seen in Figure A.5 in the Appendix, the average funding ratio of occupational defined benefits pension plans in Portugal was 106% in 2012, and 103% in 2016, which means that the assets cover the liabilities of the plans on average. It can also be seen that in general there are no significant differences in the funding ratio from 2012 to 2016 for the selected OECD countries.

The valuation methodology of assets and liabilities is a key issue to assess the financial position of a pension fund and to compare its performance over the time. To compare different funds at a certain point in time, it is necessary to carry out an evaluation of the impact of different accounting standards.

Figure A.6 presented in the Appendix shows the allocation of private pensions funds by asset type in Portugal for 2016. Bills and bonds are the more representative, being 56% of the assets, followed by 19% in shares, 18% in cash and deposits, and 7% for others.

When applying an ALM model to a pension fund and when choosing an investment portfolio, the basic concepts to apply are the assurance of risk-efficient and well-diversified portfolios. Considering that the efficiency of a fund is dependent on the portfolio selection, the buffer capital, and the target funding ratio, a key component of the ALM problem is the identification of the features that impact the risks and returns – including the quantification of the effect of each possible decision, based on different risk return measures. According to Markowitz (1952), a decision is more efficient than others if it results in a higher-than-expected return for the same level of risk, or in lower risk for the same level of expected return.

ALM includes the development of future evolution scenarios for pension fund assets and liabilities, based on certain assumptions about economic, financial, and biometric variables (Blome et al.,2007).

A pension board has at its disposition a wide variety of instruments to manage the funding ratio, whilst always taking in consideration the interests of the involved parties, namely the: pension policy, pension system, indexing policy, reinsurance policy, investment policy, and contribution policy. Subject to effects on the liability side, the pension policy comprises the different decisions regarding the pension fund, whilst pension system are the rules concerning the payment of the benefits. The indexing policy is a key factor in the valuation of liabilities and future benefit payments and, finally, the reinsurance policy is related with the possibility of a pension fund being able to sell part of the risks to an insurance company. With regards the assets valuation, the contribution policy is connected to the possibility of changing the contribution rate, whilst the investment policy involves the decision regarding in which asset classes the fund should be invested (Cannas, 2010).

4. ALM models for pension funds

In this section we present a brief description of some of the ALM models that are applied to achieve an optimal asset allocation for a certain desired level of risk-return and the evolution over the years.

4.1. The evolution of ALM models

ALM for pension funds has its origins in the 19th century, for at that time it was the insurance companies that were responsible for managing pension funds and it was only later that the sponsors had the autonomy to lead investment decisions. The funds were invested in fixed-income products, with the objective being the matching of assets with liabilities for cash-flows. According to Seburn (1991), this methodology was used for nearly a century, from the 1870s up until the 1960s.

The ALM modelling for pension funds, while recognising quasi-independent investments, had its beginning with the Dedication model. Leibowitz was responsible for this approach – where the matching of assets and liabilities remains the main objective, with the name of the model being derived from the logic that each cash inflow is dedicated to paying a specific cash outflow (Leibowitz, 1986). Another key point early on was to invest the entire portfolio in bonds, whilst simultaneously assuring the required cash flows over the time horizon of the problem. The advantages of the Dedication model are the following: the reduction of risks, the absence of problems regarding decisions of asset allocation, passive management, the objective is well-known (the matching of cash-flows), and the fact that cash flows are easily predictable. On the other hand, the disadvantages included: the complex mathematical models, the difficulties of construction, the need for accurate projected liability benefit payments and future values to match with all the uncertainties. Additional drawbacks include the limited active role of bond managers and pension consultants who are specialised in asset allocation, as well as a high sensitivity to interest rates (Leibowitz, 1986).

During the 1980s, the Dedication model was replaced by the Immunisation model, which consists in matching the impact of interest rate movement on the present value of liabilities with the duration of assets[3]. This model applied the principle of Macaulay (1938) as its objective – namely to minimise the volatility of the surplus (the excess of the value of the assets of a pension fund over the value of the plan's liabilities) by having the same duration for assets and liabilities. If the duration of the bonds held in a portfolio were matched with the duration of the liabilities that would be funded by those bonds, then the effects of interest rate changes would consequently be completely mitigated – which explains the origin of the name 'immunised'. This approach was ignored until the advent of the long trend of increases in interest rates, whereby the financial sector was forced to pay attention to the advantages of this model. Knowing that high interest rates would lead to locking high interest rates, pension fund managers incorporated the dedication model first, and then immunisation model (Fong and Vasicek's, 1984).

[3] The duration of a financial asset that consists of fixed cash flows, for example a bond, is the weighted average of the times until those fixed cash flows are received, in which the time of receipt of each payment is weighted by the present value of that payment. When the price of an asset is considered as a function of yield, duration also measures the price sensitivity to yield, the rate of change of price with respect to yield or the percentage change in price for a parallel shift in yields.

Until the early 1980s, the use of these models in ALM resulted well, but then interest rates began to fall and the risks of using dedication and immunisation models became too great. As a solution, Leibowitz and Weinberger (1982) adjusted these models to the Contingent Immunisation model, which can be seen as a form of portfolio insurance. In this approach, the portfolio stays in an active management mode, while the portfolio asset value is maintained above a certain level and it enters into an immunisation mode when the asset value falls below that value. The basis of these models is cash-flow matching, where an accurate discount rate is essential, as it is used to compute the present value and the duration of a liability.

These earliest ALM models are commonly called ‘deterministic’, as in these approaches future cash flows are estimated and are assumed to be certain. New models were then developed, the main difference from the preceding models being the stochastic future stream of benefit payments, although the optimal portfolio continued to be obtained by the use of duration matching techniques. Other examples of these models are Cox et al. (1985) and Norris and Epstein (1989). Deterministic methods have proved to be inefficient, due to certain problems, which are mainly related to difficulties in managing uncertainty.

It was only in the late 1980s that the Simulation model started to be used to solve ALM problems, as can be seen in Van der Meer (1989). This method became popular, as it incorporated the creation of a wide number of possible scenarios for the evolution of the financial position. Another important feature of the simulation method is the incorporation of the long-term investment horizon of about 30 years, which requires a model to be dynamic and to include the restrictions of supervisory entities. On the other hand, an important disadvantage of the use of simulation is that many parameters have to be decided upon.

A possible way to overcome the simulation problems is the use of Stochastic Linear Programming models, where, instead of being exogenous, the decisions are now endogenous to the model. The problem of uncertainty is incorporated by stochastic methods – mainly by using surplus optimisation.

Over the last decades, new models have been developed for stochastic programming, these techniques are complex and flexible and are a principal tool for the efficiency of ALM. Consigli and Dempster (1998), Kusy and Ziemba (1986), Kouwenberg and Zenios (2006) are examples of some of the authors who applied multistage stochastic programmes to ALM for pension funds.

During recent years, ALM models have become more complex, moving from the one-period static type to multi-period dynamic models. These more sophisticated models involve the consistent stochastic simulation of assets and liabilities, through the running of Monte Carlo simulations. This scenario analysis is also widely used in ALM to model economic risk and return factors, as it simulates multiple scenarios of the future development of economic variables and then assesses the impact on the objectives. The simulation scenario model starts by exploring how ALM strategies behave in various scenarios, whilst taking into consideration the inherent costs and the risks. Different risks and returns are then computed, according to each strategy. Next comes the phase of evaluation and decision making. This whole process is continuously carried out until an optimal strategy is encountered which maximises the risk-returns for the pension fund, sponsors, and the trustee. Scenario analysis is sometimes preferred over other approaches, on account of its flexibility, as it does not just provide the optimal solution – as it is possible to explore more than one scenario and the facility with which the decision makers interpret the results and use them in a practical way, rather than just as a theoretical experiment (Gallo, 2009).

The principles of scenario analysis are the incorporation of external uncertainties. For example, interest rates, equity market value, inflation and actuarial factors are all used to build scenarios which represent hypothetical future developments. The accuracy of the generated scenarios and the evolution of the parameters are a key factor for the modelling process and the subsequent decision-making process. Scenarios based on the economic situation simulate the evolution of macroeconomic variables, such as long-term interest rates and inflation. Financial markets variables are then incorporated into the equation, such as, for example, yield curve, dividend yields, stock indexes, and currency exchange rates.

In summary, a wide range of methods are used in ALM, all of which can be classified into four main categories: stochastic programming, dynamic programming, portfolio theory, and stochastic simulation. Before entering into more detail, it is important to bear in mind that the process of ALM modelling can be quite challenging and that most of the models are too demanding to actually be applied in practice.

4.2. ALM optimisation using simulation – Yu, Huang, Chen and Lin (2012)

The research developed by Yu et al. (2012) is a multi-period discrete-time asset liability optimisation, using a simulation model, which includes an evolution strategy algorithm to create a defined contribution pension plan that is capable of matching the target liability and of decreasing the downside risk. The advantages of a multi-period asset allocation relative to a single period, is that it supports underfunding for a longer time, which tends to improve investment returns when considering the entire period. The objective of Yu et al. (2012) was to find an effective asset allocation to pay the pension benefits. With the results of the model, fund managers and investors can evaluate their targets and then meet their obligations. Should the market conditions have changed after an investment period, the model must be estimated again to obtain the new effective asset allocation for the rest of the period. As the liabilities of a pension fund are long-term, the investment horizon must consider a long planning investment horizon.

The equation used to evaluate the assets' value of the portfolio at maturity is given by:

$$A(n) = \sum_{t=1}^{n} c\% \times S_t \prod_{i=t}^{n} \left[\sum_{j=1}^{4} P_{ij} \times (1 + r_j(i))\right]$$

where P_{ij} is the proportion of each asset j in time i;

A(n) is the value of assets in the end of the term;

c% is the contribution rate;

S_t is the salary in year t;

rj(i) is the investment return of asset j in time i.

As only four asset classes were considered for this model, j=1,2,3,4.

The matching of assets and liabilities adopts a conservative approach and is a very sensitive objective. A possible way to overcome this problem is to define the target liability – L(n) – by using income replacement rate as an index, which can be defined as:

$$L(n) = 80\% \times S_x \times \ddot{a}_x$$

Where S_x is the salary at age x, x is the retirement age, and $\ddot{a}_x$ is the value of an annuity of 1 per annum, payable annually in advance for a life attaining age of x.

The authors incorporated the investment performance during the accumulation period by setting this performance level every year, whereby the target liability must increase in value at the most between 5% and the inflation rate for year t (rpi_t). Accordingly, the target liability at time t can be computed as:

$$L(t) = [L(t-1) + c\% \times S_{t-1}] \times max\{1.05, rpi_t\}$$

With L(0)=0 and t=1,…,n-1.

The investment portfolio can be restructured for each five-year period. As a simplification, if the proportions could be changed every year, this would be computationally demanding. Consequently, considering all these afore-mentioned factors, the objective function is:

$$\text{Min}\,\theta \times E\left[\left(A(n) - L(n)\right)^2\right] - \sum_{k=1}^{k=\frac{n}{5}-1} E[A(T_k) - L(T_k)]$$

Where θ reflects the importance of the matching of assets and liabilities at the time of retirement. The objective function incorporates the minimisation of the tracking error in the terminal date and the need to reduce the downside risk.

The inputs of the objective function are the contribution rate and the proportion of the asset classes in the consecutive portfolios. Yu et al. (2012) started their calculations by determining the strategic portfolio composition, to subsequently simulate 4,000 scenarios for the future asset returns for the next 40 years. The model aims to help define a contribution rate and the portfolio composition over time. The conclusion of the scenario-based simulation are that more risky investments lead to higher returns and a lower contribution rate, but they are at the same time responsible for greater losses.

Later, during the first years of the portfolio, investment in stock markets should be preferred and this should be gradually replaced with investments in assets that have less risk up until the time of retirement. It can thus be seen that the optimisation model can represent promising results for helping managers and investors achieve greater returns or for reducing the level of risk in their investment decisions.

4.3. Robust Optimisation – Platanakis and Sutcliffe (2017)

Another relatively new technique in ALM for pension funds is robust optimisation. This method recognises that the market parameters of an ALM model are stochastic, however they are located within certain sets of uncertainty. In recent years, this method has attracted attention and is recognised to be a powerful and efficient technique for solving ALM problems when applied to portfolio optimisation and asset management.

The robust optimisation method solves the maximin optimisation problem, as it assumes that each stochastic parameter assumes the most unfavourable value in its uncertainty set. Furthermore, it has the advantage of being much easier to solve than stochastic programming, which is more demanding computational-wise. This solution tends to eliminate extreme solutions and consequently originates investment in diversified portfolios.

Platanakis and Sutcliffe (2017) assume that the stochastic assets and liabilities are described by the following factor model:

$$\tilde{r}_{A,L} = \tilde{u}_{A,L} + \tilde{V}^T f + \tilde{\varepsilon}_{A,L}$$

Where,

$\tilde{r}_{A,L}$ is a joint column vector with n_A+n_L elements that contains asset and liability returns;

$\tilde{u}_{A,L}$ is a joint column vector with n_A+n_L elements that contains the random asset and liability returns that drive the risky assets and liabilities;

f is the column vector with m (number of factors) elements containing the factor returns that drive the risky assets and liabilities;

$\tilde{V}$ is the matrix with m rows and n_A+n_L columns containing the corresponding uncertain factor coefficients;

$\tilde{\varepsilon}_{A,L}$ with n_A+n_L elements is the column vector of uncertainty disturbances.

The $\tilde{V}$ is part of an elliptical uncertainty set denoted by S_u. The elements of $\tilde{u}_{A,L}$ and the diagonal elements of the covariance matrix of the disturbances $(\widetilde{D})$ lie within certain intervals which are represented by the S_{mean} and S_d uncertainty structures, respectively. These parameters depend on *w* that represents the level of confidence.

As this is a factor model, one of the advantages is that there is no need to estimate the covariance matrix of the asset-liability returns, but just the covariance matrix of the factor returns.

The robust optimisation problem *we* is given by the following maximin problem:

$$\underset{\Phi_A}{\text{maximise}}\left[\frac{min_{\{\tilde{u}_{A,L}\in S_{mean}\}}\left[\tilde{u}_{A,L}^{T}\Phi_{A,L}\right]}{\sqrt{max_{\{(\tilde{V}\in S_u)\}}\left[\Phi_{A,L}^{T}\tilde{V}^{T}F\tilde{V}\Phi_{A,L}\right]+max_{\{\widetilde{D}\in S_d\}}\left[\Phi_{A,L}^{T}\widetilde{D}\Phi_{A,L}\right]}}\right]$$

subject to: $1^T\Phi_A = 1,$

$$\Phi_{A,i} \geq 0, \qquad \forall i = 1, \dots, n_A,$$

$$-\sum_{i\in classX}\Phi_{A,i} + \Theta_{max}^{classX}1^T\,\Theta_A \geq 0, \qquad \forall classX,$$

$$\sum_{i\in classX}\Phi_{A,i} + \Theta_{min}^{classX}1^T\,\Theta_A \geq 0, \qquad \forall classX$$

Where $\phi_{A,L}$ denotes the joint column vector of asset proportions ϕ_A and liability proportions ϕ_L. Θ_{min}^{classX} and Θ_{max}^{classX} are the minimum and maximum values for each asset class X, with X equal to equities, bonds, real estate, and others.

The objective of this function is to maximise the Sharpe Ratio under the worst circumstances – the maximin. The numerator is the worst-case mean return and the denominator is the worst-case variance, both of which depend on the parameter *w*, whereby as this parameter is increased, the size of the uncertainty set also increases.

The authors used three benchmarks. The first is the actual portfolios chosen by the (Universities Superannuation Scheme) USS fund. The second is a modified version of the Sharp and Tint model (Sharpe and Tint, 1990), where the objective function maximises the expected return on the asset portfolio in excess of the liability portfolio, divided by the standard deviation of these excess returns, which is given by:

$$\underset{\Phi_A}{\text{maximise}} \frac{\Phi_{A,L}^T \mu_{A,L}}{\sqrt{\Phi_{A,L}^T \Sigma_{A,L} \Phi_{A,L}}}$$

subject to: $1^T \Phi_A = 1,$

$$\Phi_{A,i} \geq 0, \qquad \forall i = 1, \dots, n_A,$$

$$-\sum_{i \in classX} \Phi_{A,i} + \Theta_{max}^{classX} 1^T \, \Theta_A \geq 0, \qquad \forall classX,$$

$$\sum_{i \in classX} \Phi_{A,i} + \Theta_{min}^{classX} 1^T \, \Theta_A \geq 0, \qquad \forall classX,$$

where the $\Sigma_{A,L}$ is the sample covariance matrix of the assets and liabilities returns.

The last benchmark is the Bayes-Stein estimation (Jorion, 1986). In this approach, the estimates of the inputs for a portfolio problem are based on the knowledge that estimated returns with a higher distance from the norm have a higher chance of containing estimation errors than estimated returns close to the norm. To confront these errors, the estimation of the input parameters are the weighted sum historic returns for each asset and a global estimate of returns.

The fact that the robust optimisation method has as its objective those maximin means that tend to have a better performance than other techniques when the market falls, with the opposite occurring in a rising market. At the end, an evolution of the performance of the various approaches is carried out to find the best solution.

Platanakis and Sutcliffe found that the robust optimisation method outperformed the benchmarks in almost every time period.

5. Analysis of a pension fund

In this section, a brief analysis of the Banco de Portugal defined benefit pension fund is carried out, based on the Report and Accounts of the fund. This closed fund was created in 1988 and is exclusively destined to the fulfilment of the obligations of Banco de Portugal (sponsor) with its defined benefit pension plan. After 2014, the fund is also responsible for a health benefits plan.

To describe the fund population, by the end of 2017 the pension plan had 1,054 active members and 2,567 beneficiaries, while the health benefits plan had 1,755 active members and 2,512 beneficiaries. The integration of the Bank's employees who were hired after March, 2009 in the State social security system and the consequent closure of the pension plan to new members, have contributed to the increasing tendency of the reduction of the ratio of active members/beneficiaries over the last years. This translated into a higher weight of the payment of the pensions in the total liabilities, which consequently restrains the investment policy of the fund.

In 2017, the age limit for paying out the pension for this fund was 65 years. In 2017, 61.2% of the liabilities were related to retirees, and 38.8% to active members. In 2017, the ALM of the fund generated financial earnings of 1.5% of the liabilities, based on the position taken relatively for both assets and liabilities.

Figure 5.1 shows the evolution of the fund value. When considering the last years, it is possible to conclude that in general, the BdP defined benefit pension fund tends to increase over time, and, in comparison to the value of 2008, it had experienced a significant increase by 2017, representing the third largest fund in Portugal, after Grupo Banco Comercial Português fund and Pessoal da Caixa Geral de Depósitos fund, both closed funds.

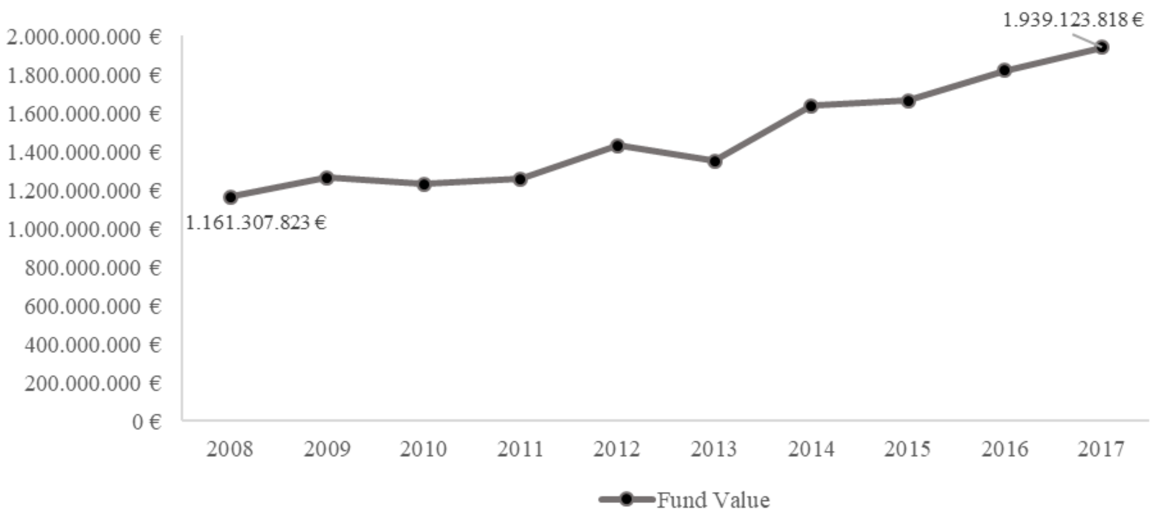

Figure 5.1 - Evolution of the value of the BdP defined benefit pension fund, 2008 to 2017

The evolution of the contributions and the value of pensions paid since 2008 can be observed in Figure 5.2. On the one hand, the value of pensions paid has slightly increased over the years, albeit without significant variations. On the other hand, the value of the contributions demonstrates a large degree of variability, and, for some years, to enable the fund to meet its obligations, as the sponsor, Banco de Portugal has been obliged to pay in some additional contributions. Additionally, it is important to refer that in the specific case of this pension fund, all the contributions are paid in by Banco de Portugal, and none by its employees ('non-contributive').

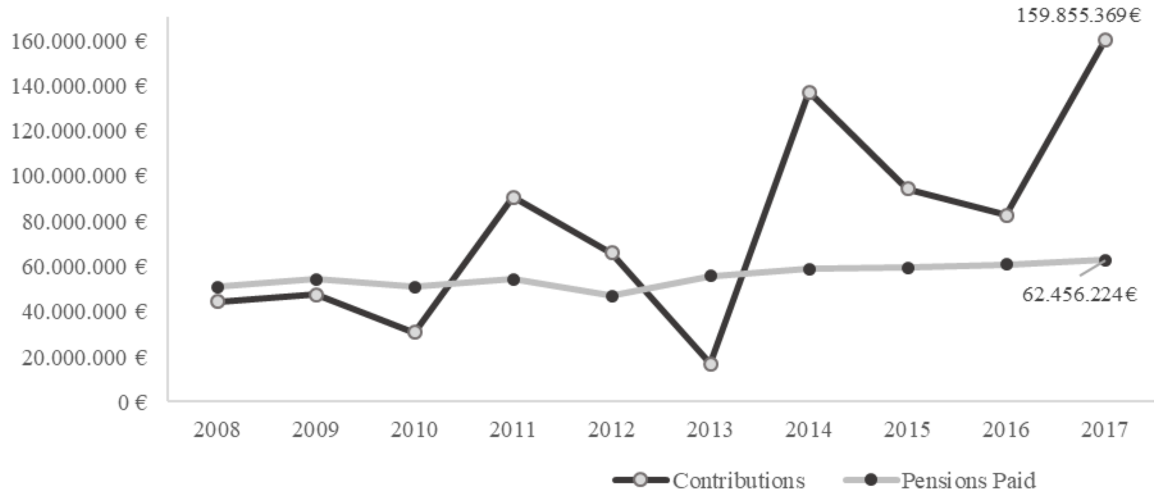

Figure 5.2 - Evolution of the contributions of the BdP defined benefit pension fund and the value of pensions paid out, 2008 to 2017

Based on the actuarial valuation, it can be seen that there has been a significant increase in the total liabilities of the fund over the years, as can be observed in Figure 5.3. The liabilities can be split into two parts: the liabilities with active contributors and retirees (which were 737,353,283€ and 1,160,793,477€, respectively in 2017).

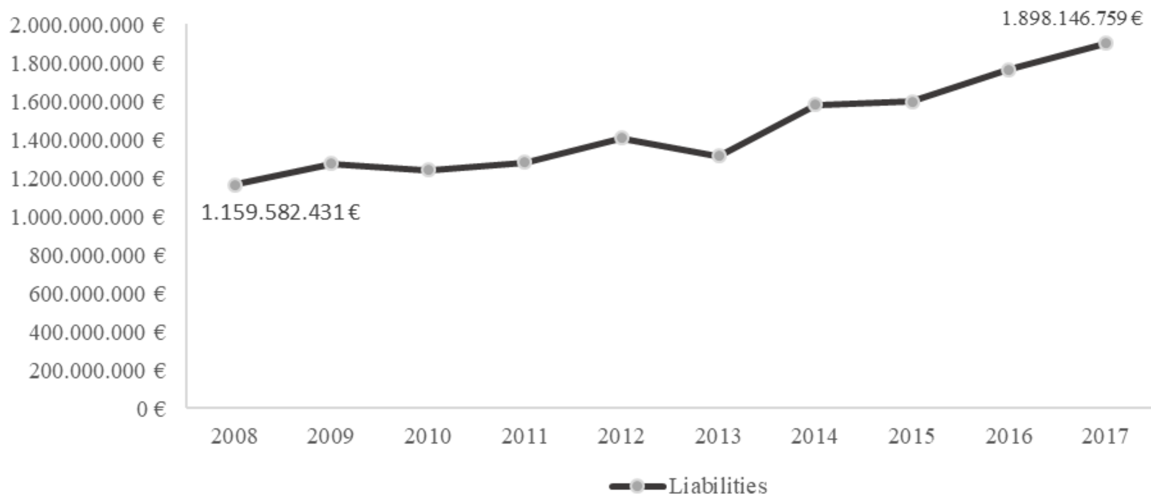

Figure 5.3 - Evolution of the liabilities of the BdP defined benefit pension fund, 2008 to 2017

Another important fact regarding 2017 was the increase of 7.7% in the Liabilities – which was largely due to the change in the mortality assumption (+12%).

As shown in Figure 5.4 and Table 5.1, the asset allocation at the end of 2017 for the main investment products were bonds (82.9%), real estate (8.6%), stocks (7.4%), and liquid assets (1.1%). As a high percentage of the fund is invested in bonds and a relatively low percentage is invested in stocks, it can be concluded that this fund is more concerned with minimising risks, than maximising returns. With regards the investment policy, the major part of the fund is invested in instruments with interest rates in the Euro Area, followed by instruments in the real estate market, instruments in the stock market, and, lastly, liquid assets. By undertaking an overviewing of the fund's investments, it can be seen that over the years the fund has maintained high exposure to the Euro Area countries, and that the exposition to other geographic areas is mainly investment in stock markets and private debt. Accordingly, the cambial risk is very low.

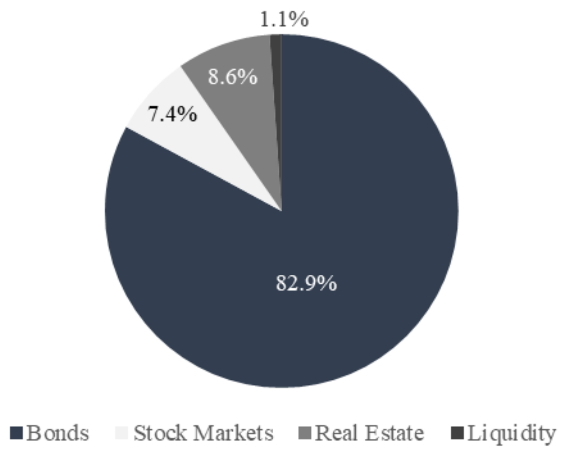

Figure 5.4 - Asset allocation by asset class of the BdP defined benefit pension fund, 2017

Table 5.1 – Investment portfolio of the BdP defined benefit pension fund (2017)

Bonds	82.9%
Public Debt Indexed to inflation	66.1%
Public Debt at a fixed Rate	16.5%
Public Debt	0.3%
Stock Markets	7.4%
Euro Area	2.1%
Europe Except Euro Area	1.4%
Asia-Pacific	0.4%
North America	2.9%
Emerging	0.6%
Real Estate	8.6%
Funds	1.7%
Real Estate Properties	6.9%
Liquidity	1.1%

It is possible to see in Figure 5.5 that over the last 10 years, the BdP defined benefit pension fund has always achieved a funding ratio above the minimum funding ratio defined by BdP regulation. The difference of the value obtained compared to the minimum required was at its lowest in 2011.

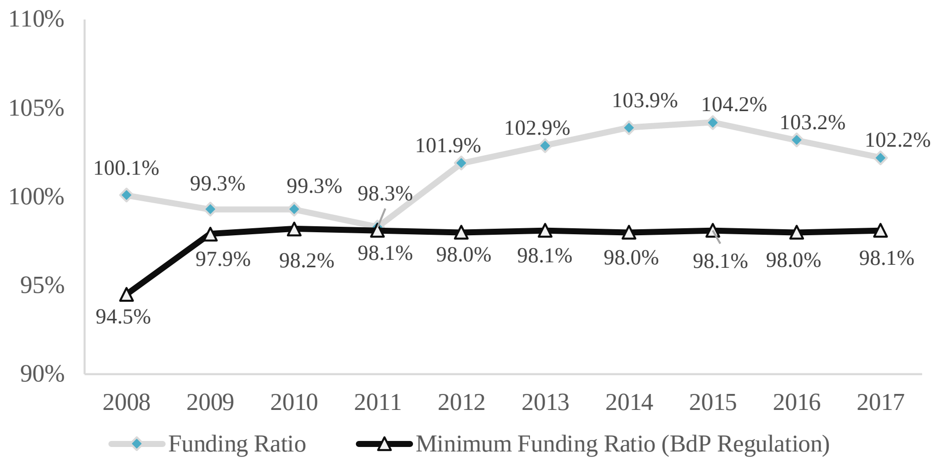

Figure 5.5 - Comparison between the minimum required funding ratio and the funding ratio of the BdP defined benefit pension fund from 2008 to 2017.

From Figure 5.5 above, it can be concluded that the ALM strategy applied by the BdP defined benefit pension fund has been successful, and that since 2012 the assets of the fund have completely covered the liabilities. The funding ratio in 2016 of the BdP defined benefit fund is in line with the average funding ratio of private occupational defined benefit funds in Portugal of 103% (see Figure 10 in the Appendix).

Although the type of ALM model used by the BdeP fund is not public knowledge, it can be concluded from these values that the ALM model chosen probably has as its objective the matching of assets with liabilities, based on the fact that the funding ratio does not vary significantly from 100% over the years analysed.

6. Conclusions

Over the years, Asset Liability Management has become an essential instrument for a pension fund manager to assure the mitigation of risks and maximise returns. As the pension funds optimisation problem became increasing more complex, more sophisticated models have been developed to incorporate all the factors involved and thus enable the carrying out of an accurate ALM exercise.

The approach used for ALM depends on whether the pension fund is a defined benefit or a defined contribution pension plan. In the case of a defined benefit plan, the objective of ALM is generally to match assets with liabilities, although sometimes more complex optimisation exercises are carried out to ensure the maximization of returns. On the other hand, in the case of defined contribution plans, as the benefits are not defined, the principle applied is usually to give preference to investment in risky assets during the first years, and later replace them with less risky assets as retirement time draws close.

The two models described in this paper were chosen after carrying out an extensive review of the literature in this area. In first place, the optimisation using Simulation model (Yu et al., 2012) is applied to defined contribution pension funds. In this model, the benefits are not defined and the target liability for the end of the investment horizon is set based on the replacement rate. The simulation consists in running 4,000 simulations for the future returns of the assets, which helps define the composition portfolio and the contribution rate.

The second model studied was the Robust Optimisation model (Platanakis and Sutcliffe, 2017), which can be applied to defined benefit pension funds. This model assumes that the market parameters are stochastics and that the objective is to maximise the worst-case scenario and find the right portfolio allocation for this purpose. Platanakis and Sutcliffe (2017) compared the results with three benchmarks and show that robust optimisation has the best outcomes. The main advantage of the robust optimisation is that it is easier to solve than stochastic programming, and it also eliminates extreme solutions, which results in the creation of a well-diversified portfolio.

The analysis of these models in this paper contributes to understanding the differences of ALM modeling for each type of pension plan. In the case of the defined benefit plan, the benefits are set, and consequently the fund is liable to experience certain difficulties in meeting its obligations. However, these difficulties can be mitigated by the use of ALM modelling, which subsequently helps the fund achieve its objective. In the case of the defined contribution fund, this type of plan is more flexible and ALM modelling should be employed to assure the minimising of the contribution rate and the optimization of the portfolio selection.

With regards the analysis of the BdP defined benefit pension fund, in the light of the good results achieved over the years under analysis, it can be concluded that this fund is employing a successful ALM strategy.

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Appendix

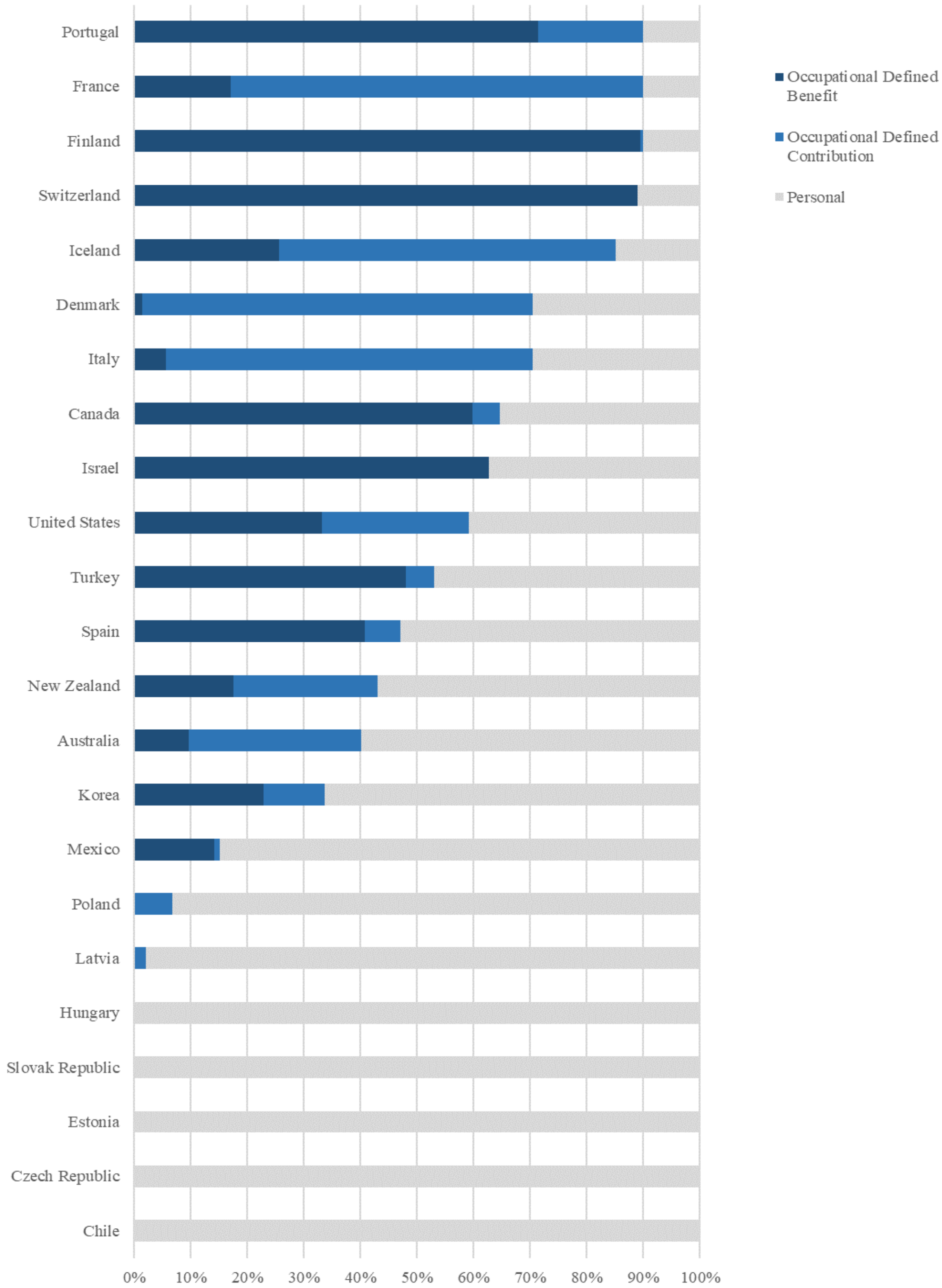

Figure 0.1 - Pension funds' assets by type of private pension plan in the selected OECD countries,2016. Source: OECD (2017)

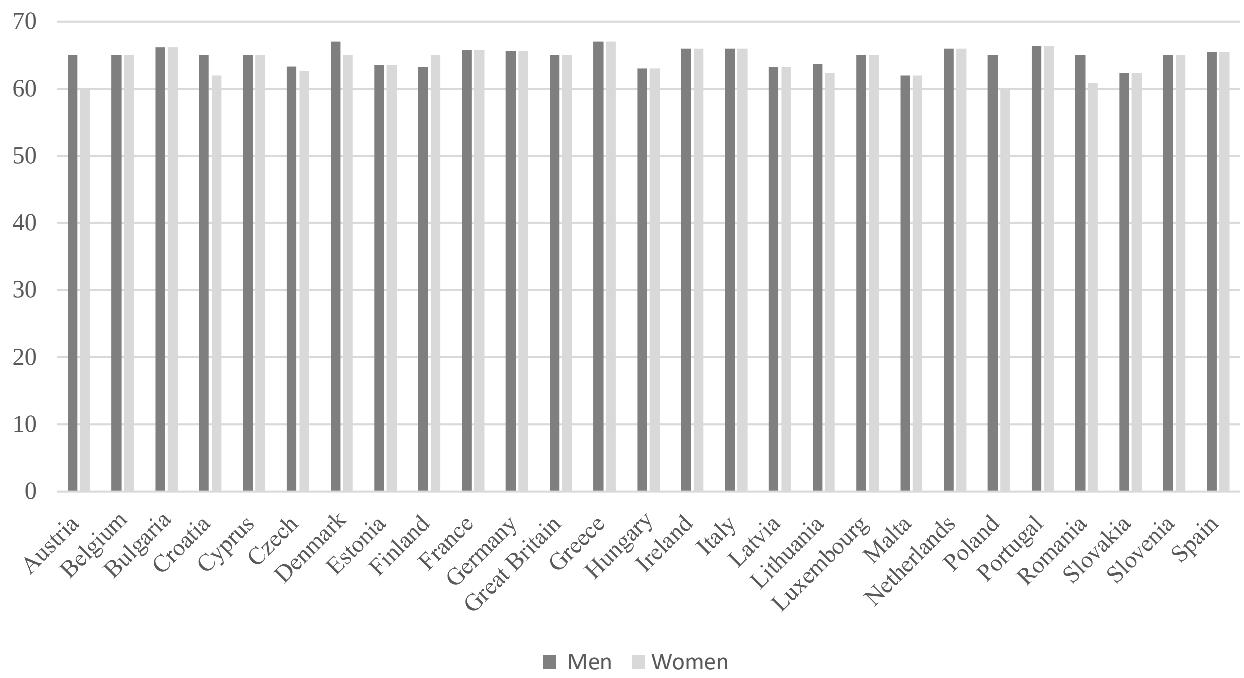

Figure 0.2 - Legal retirement age in European countries, 2018. Source: https://www.etk.fi/en/the-pension-system/international-comparison/retirement-ages/

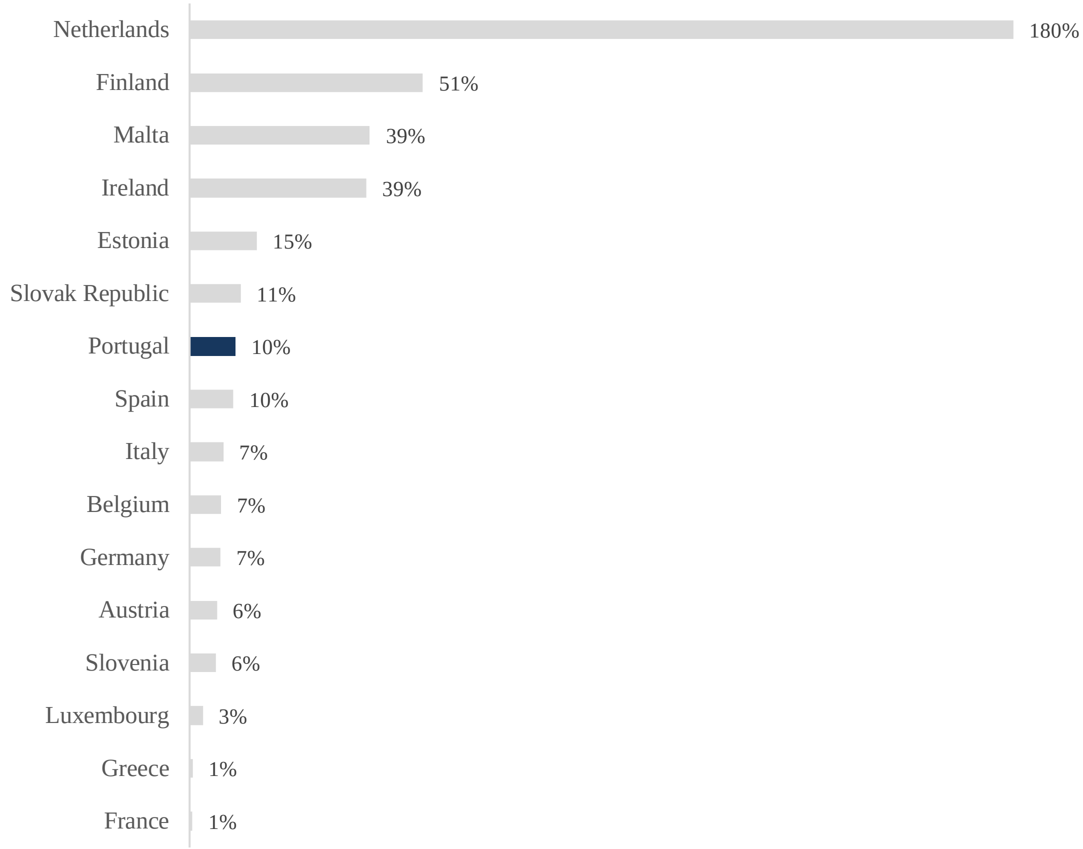

Figure 0.3 - Pension funds' assets as a % of GDP in Euro Area Countries, 2016. Source: OECD (2017)

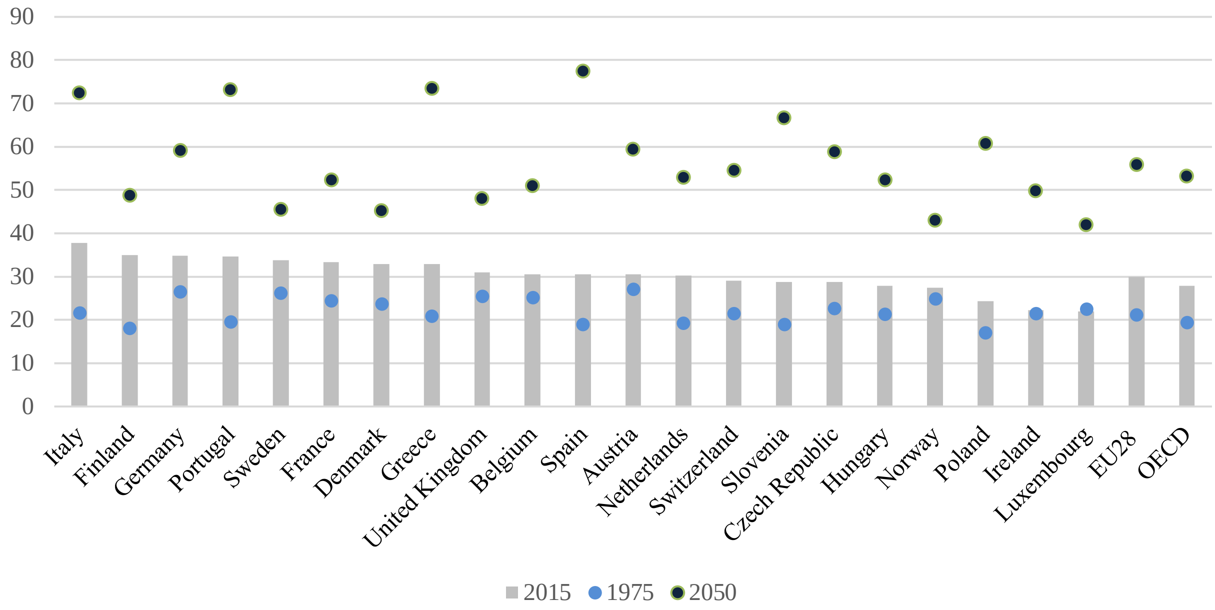

Figure 0.4 - Comparison of the old-age dependency ratio (number of people older than 65 years per 100 people of working age, 20-64) for the selected EU28 and OECD countries. Source: OECD (2017)

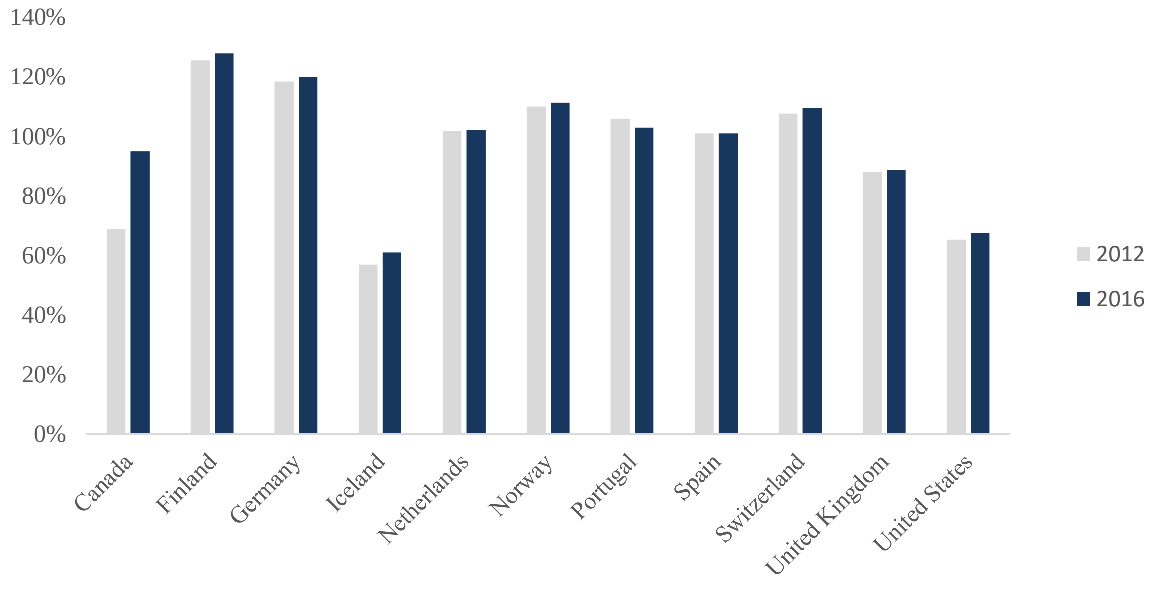

Figure 0.5 - Average funding ratio of occupational defined benefits pension plans in selected OECD countries, 2012 and 2016. Source: OECD (2017)

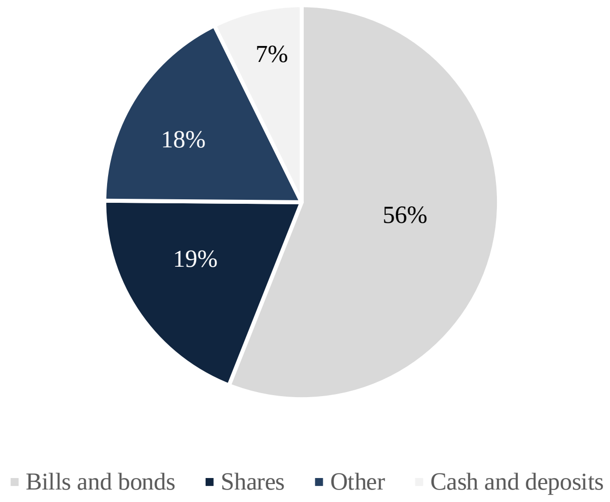

Figure 0.6 - Allocation of private pensions' assets in Portugal, as a % of total investment (2016).
Source: OECD (2017)