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Evaluating the UK and Dutch defined-benefit pension policies using the holistic balance sheet framework☆

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ABSTRACT

This paper compares the UK and Dutch occupational defined-benefit pension policies using the holistic balance sheet (HBS) framework. The UK DB pension system differs from the Dutch one in terms of the steering tools and adjustment mechanisms. In addition to the sponsor guarantee, the UK system has the protection from the Pension Protection Fund (PPF) that guarantees DB pension schemes' funding shortfalls if the sponsors of the schemes are insolvent. The paper first introduces a multi-period model called value-based ALM to value the embedded options implied by both UK and Dutch pension policies and build the HBS. The HBS framework allows us to have a holistic view on the real and contingent assets and liabilities of a pension scheme and evaluate the impact of introducing a new policy for the stakeholders of the pension scheme. Then, we compare the results of a typical UK policy with a typical Dutch one. The comparison suggests the UK policy is better for participants but worse for the sponsor compared to the Dutch policy. The UK policy is more generous in indexation and participants do not have the burden to contribute to the funding recovery of the pension scheme. The PPF provides protection of the benefits up to a certain level if the sponsor is insolvent, thus, participants in a scheme with a UK pension policy are exposed to limited downside risk. On the other hand, the sponsor of the pension scheme with the UK policy shoulders a heavier burden to contribute to the recovery of the pension funding shortfalls than that of the pension scheme with the Dutch policy.

1. Introduction

1.1. Research background

The second pillar pension plans in Europe vary considerably in size, pension promises, finance method, etc. The regulation and supervision of the pension funds also differ greatly. This diversity makes it difficult to compare plan designs and regulation burdens across countries fairly. To harmonise the framework of quantitative requirement for European pension funds, the European Insurance and Occupational Pension Authority (EIOPA), the European pension regulator, introduced a "holistic balance sheet" approach.

Unlike the traditional balance sheet (TBS) that states only the real assets and liabilities, holistic balance sheet (HBS) also takes into account contingent assets and liabilities implied by pension policies. These contingent assets and liabilities are called embedded options, as their values depend on the market conditions, like derivatives. Therefore, the derivative asset pricing approach can be employed to value the embedded options. The HBS presents the values of both real and contingent assets and liabilities, providing a "holistic" view of the pension fund status.

The development of the quantitative framework using the HBS approach is still in its early phase. EIOPA (2013) recently published the preliminary results of the Quantitative Impact Study (QIS), which conducted the HBS studies for the defined-benefit (DB) pension funds across eight European countries. The results shed some

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light on the impact of different pension policies across the countries.

This paper builds the HBS for UK and Dutch pension policies, respectively. By presenting the contingent assets and liabilities alongside real assets and liabilities, we compare the impact of each policy on the stakeholders of the pension fund. The results demonstrate that the HBS framework does provide an appropriate quantitative method to compare pension policies with different features.

1.2. Features of UK pension policies

According to EIOPA (2013), UK has the largest private sector DB occupational pension scheme market in Europe with around £2 trillion of pension scheme assets. There are around 11.7 million members in total, including 2.1 million active members, in the DB pension schemes.

Pension Protection Fund

One special feature of the DB pension schemes in UK is that almost all schemes in this group are eligible for the UK Pension Protection Fund (PPF) protection. The PPF was established in 2005 to protect members of private sector DB pension schemes in the event of pension scheme underfunding when the sponsor of the pension scheme becomes insolvent. The PPF guarantees full amount of the pensions in payment and 90% of the deferred pensions.[1] The total amount is also subjected to a cap set by the PPF annually. Once the sponsor declares insolvency, the trustees of the pension scheme start to apply for the PPF protection and trigger an assessment period. During the assessment period, the PPF acts as a creditor to the insolvent sponsor of the pension scheme, and tries to retrieve some assets to mitigate the pension deficit. Meanwhile, the pension scheme in concern tries to quote life insurance contracts that pay each member at least their accrued PPF guaranteed benefits. If the remaining assets from the pension scheme can afford such contracts, the life insurance will be bought for each participant and the PPF stops to be involved. Otherwise, both the assets and the liabilities of the pension scheme and its participants will be transferred to the PPF. From then on, the PPF will pay the guaranteed amount of accrued benefits to participants when they retire.

The PPF charges each eligible pension scheme an annual premium (called the levy). The size of this premium depends on the size of the scheme and the level of risk in the scheme, including the pension funding shortfall, the credit risk of the sponsor, and the investment strategy of the pension scheme.

The assets of the PPF consist of the premiums the PPF charges eligible schemes, the assets from the taken-over schemes, the assets retrieved from the insolvent sponsors, and investment returns of the PPF. The liabilities of the PPF are the present value of the guaranteed benefits of the participants of the schemes that are taken over by the PPF. The liabilities will potentially increase in the future if the PPF takes over more pension schemes.

Since 2008, the turbulent financial markets and economic slowdown lead to funding shortfalls in many UK pension schemes and increased number of company insolvencies. As a result, the liabilities of the PPF surged. The PPF had to increase the premiums it charges eligible schemes to achieve its long term self-sufficient funding target (PPF, 2012a). This paper addresses the issue of how the PPF policy affects an individual pension fund, thus, we leave out the discussion of the viability of this pension guarantee mechanism.

[1] The pensions in payment mean benefits paid to the pensioners and the deferred pensions refer to the accrued benefits that will start to be paid to participants when they retire.

Indexation

Another particular feature of the UK pension system is that benefits must receive statutory pension increases in payment. The indexation to increase benefits each year used to link to the retail price index (RPI) and switched to the consumer price index (CPI) in recent years. The indexation is capped at 5% for the pensions in payment and 2.5% for the deferred pensions. A number of pension schemes also provide guaranteed pension increases in addition to the statutory requirements. It should be noted that indexation for the benefits paid out from the PPF is capped at 2.5%.

Recovery plan

UK DB schemes are subject to the Pension Act 2004, stating that "every scheme is subject to the statutory funding objective" to "have sufficient and appropriate assets to cover its 'technical provisions' ". The technical provision is the assets that are required to make provision for the pensions in payment and deferred pensions. If there is any funding shortfall at the effective date of each actuarial valuation, a so-called recovery plan must be prepared and agreed upon between the trustees and the sponsor(s) of the pension scheme. The recovery plan aims for any shortfall to be eliminated as quickly as the sponsor can reasonably afford. It consists of streams of annual cash flows that can span many years. A typical recovery plan in UK lasts between 5 and 10 years with a median of 8 years. Some pension schemes have a recovery plan length of more than 17 years and some have a recovery plan length of shorter than one year.

As one can see, the only steering instrument available to the pension trustees in UK is the recovery contribution from the sponsor(s). The PPF does provide securities to participants of the pension scheme, but only after the scheme is liquidated. These policies have very different characteristics from the instruments available to the pension funds in the Netherlands.

1.3. Features of Dutch pension policies

The private sector DB occupational pension system in the Netherlands, with assets under management of around 1000 billion Euro, is ranked highly in the world. The system consists of around 80 industry pension funds, 300 pension schemes of individual companies, and 12 pension funds for certain professionals like medical doctors. Instead of having "sufficient and appropriate assets to cover" the "technical provisions", Dutch pension regulator requires pension schemes to have an asset buffer so that the probability of underfunding in the next period is smaller than 2.5%. Several steering tools and adjustment mechanisms are available to the trustees of the pension scheme so that they can maintain the funding ratio at a healthy level. The typical Dutch policy analysed in this paper includes the following features.

Conditional indexation

Dutch pension schemes give indexations that are linked to the wage growth. Instead of full indexation, the actual indexation given depends on the funding position of the pension scheme. The trustees of the scheme set up a floor and a ceiling for the funding ratio, such that full indexation is given if the funding ratio is above the ceiling and no indexation is given if the funding ratio is below the floor. If the funding ratio is between the floor and the ceiling, the indexation is a proportion of the full indexation. The proportion equals the ratio of the difference of the actual funding ratio and the floor to the difference of the ceiling and the floor.

Sponsor support

Like its counterpart in UK, the Dutch policy also requires sponsors of the pension scheme to contribute to the recovery of funding shortfalls. How much the sponsor contributes depends on

Table 1
Features of occupational DB pension schemes in UK and the Netherlands.

UK	Netherlands
Full indexation with floor and cap	Conditional indexation
Sponsor guarantee	Sponsor support
PPF guarantee	Sustainability cut
	Employee contribution
	Catch-up indexation
	Surplus sharing

the actual funding ratio and the target funding ratio set out in the pension contracts for the sponsor to support. The sponsor pays the pension scheme such an amount that the actual funding ratio can reach the target level, given the sponsor can afford this amount.

Sustainability cut

An important difference of the Dutch policy from the UK policy is that participants also have the obligation to contribute to the recovery of the pension scheme's funding position. If the funding ratio is below the floor level required by the regulator, participants may have to bear benefit cuts so that the funding position can recover. To avoid unnecessary big losses, the recovery plan is set up for multiple years. Each year, there is a milestone for the funding ratio to recover to. If a milestone is missed in a year, participants will receive a negative indexation of their accrued benefits, so that the funding ratio can reach the milestone level. In this way, the funding ratio should reach the floor level at the end of the recovery plan.

All the three policies mentioned above depend on which part of the 'ladder' the actual funding ratio is. There are also other steering tools a Dutch pension scheme may apply, namely surplus sharing, catch-up indexation, and employee contribution. One can see that the trustees of a Dutch pension scheme have more flexibility than their counterparts of a UK scheme in terms of the selection of steering tools and adjustment mechanisms. We summarise the main features of the occupational DB pension schemes for both countries in Table 1.

1.4. Overview

The HBS approach is based on the literature on framing pension funds in terms of embedded options. An embedded option is an option or guarantee contained in a financial product. For example, the surplus sharing option may allow participants to enjoy extra benefits when there is a funding surplus resulting from better investment returns. Since the classic paper of Sharpe (1976), the contingent claim analysis has long been applied to real-life problem in the field of pension and insurance (Blake, 1998; Exley et al., 1997; Chapman et al., 2001; Kocken, 2006; Hoevenaars and Ponds, 2008; Broeders, 2010).

The study of the HBS as a tool to assess pension fund is still in the early stage. Efforts have been made in individual countries to build the HBS for pension funds with country-specific steering instruments (Kabbaj and Zeilstra, 2003; Haan et al., 2012). Our paper is the first to demonstrate that the HBS can also be used to compare the pension policies from different countries with varying features. In addition, sponsor's credit risk plays an important role in the valuation of the sponsor support and external pension protections, such as the PPF guarantee. Our paper uses the value-based ALM for the market-consistent valuation and incorporates a credit-risk model so that the embedded options depending on the credit risk of the sponsor can be valued.

1.5. The structure of this paper

This paper aims to value the embedded options in the UK and Dutch policies, and uses the HBS approach to examine the impact of each policy on the stakeholders of pension schemes. Different countries use different methods to discount pension promises and have different demographic features. To avoid complicating our analysis and comparison of policies from both countries, we will use the Dutch demographic data, mortality and morbidity rates, and the way how pension liabilities are calculated.[2]

Traditional analysis on pension fund focuses on the solvency of the fund itself. The credit risk of the employer is not taken into account when evaluating policy instruments that requires additional contributions from the employer. There are situations that the sponsor cannot afford to contribute the amount required for the recovery of the pension fund or even the solvency of the sponsor itself is under threat. Credit risk is taken into account when valuing the recovery plan and the PPF protection, for this will affect the schedule of recovery plan, the annual levy a pension fund pays to the PPF and the insolvency event that triggers the takeover of the pension scheme by the PPF.

In Section 2, we introduce a multi-period model that closely represents real-life features of a Dutch pension fund. In Section 3, we study the impact of the UK policies in the multi-period model and try to draw some conclusions of what these policies mean to the stakeholders. Section 4 presents the results of the HBS for typical Dutch pension policies, after which we will compare the HBS results of UK and Dutch policies in Section 5. We finally draw our conclusions in Section 6.

2. The model

2.1. Approach

Pension fund receives contributions and pays out benefits. The rate of the contributions and the indexation of the benefits depends on the pension contract that the pension scheme sets up with participants and the sponsor. There may be other policy features such as conditional indexation, and recovery contributions, which depend on the future economic development. Therefore, the cash flows a pension scheme faces in the future are highly uncertain. In addition, to value the guarantee options we need to take into account the credit risk of the sponsor. In a multi-period model, the time a sponsor becomes insolvent is uncertain. The evolutions of the sponsor's assets and debts are path-dependent. These complexities make it hard to develop a structural formula to value the options embedded in pension policies. Therefore, we introduce a multi-period model based on the Monte Carlo simulation, which is well-suited to solve this type of complex path-dependent valuation problems.

Value-based ALM

The model we use to value the embedded options implied by pension policies is called the value-based ALM model. It is an extension of the classic asset–liability management (ALM) model that financial institutes employ to manage the risks arising from the mismatch between assets and liabilities (Exley et al., 1997; Chapman et al., 2001; Kabbaj and Zeilstra, 2003; Hibbert et al., 2006; Zenios and Ziemba, 2007; Broeders, 2010). ALM uses risk models to generate many scenarios of the possible evolutions of pension assets and liabilities, which allows the pension scheme to calculate the probability of underfunding and gives insight into how policies, such as indexation, benefit cut, or recovery contribution impact the pension scheme.

[2] Dutch pension schemes are switched to the market-consistent method and use a term-structure of risk-free rate to calculate the present value of pension liabilities. UK pension schemes use a much higher discount rate (∼6%). However, the PPF adopts a rate that is based on market rates (for details see the annual report of the PPF (2012b)).

Classic ALM is a powerful tool to show possible outcomes of a pension scheme and enable policy makers to make well-informed decisions. But it lacks the ability to value the embedded options implied by different policy contracts. To overcome these shortages, the ALM model is extended to introduce the value-based ALM approach. Value-based ALM uses the option pricing theory to value embedded options. The contingent claims, whose payoff depends on market development, can be priced by using the deflator approach or risk neutral scenarios (Hull, 2006; Cochrane, 2005). Both approaches provide the same valuation of contingent claims. In this paper, we use the risk neutral scenarios approach to price option values. The values are added on the holistic balance sheet, thus, giving a full picture of the pension fund status.

The building blocks of the model, the valuation technique, and the assumptions required to model the sponsor's credit risk are explained in detail in Appendix A.

2.2. Pension fund characteristics

In this multi-period model, we set up a pension scheme that pays out annual benefits to the pensioners several years into the future. Many UK DB pension schemes have stopped enrolling new members, whereas most Dutch ones are still open to new participants. As our aim is to value the embedded options in the pension policies, we simplify our analysis to a closed pension scheme. Therefore, participants do not pay contributions or accrue benefits from the beginning of the first year. One can easily modify the model and adjust it to an open fund setting.

To evaluate the embedded options within the pension contracts, several variants of the pension policy are set up. Some base assumptions of the pension scheme hold for these variants and are set up as follows:

1. The pension scheme is an average wage defined benefit scheme;
2. The annual accrual rate is 2% of the member's annual salary;
3. Each member earns equal salary;
4. The pension fund has a single sponsor company;
5. The benefits received by the pension members are indexed to price level. Caps or conditional indexation applies according to individual pension policy;
6. An individual participant is assumed to enter the pension fund at the age of 25, retire at the age of 65, and can survive only up to the age of 99;
7. The pension fund asset portfolio consists of 50% bonds and 50% stocks, and is rebalanced at each time period.

The pension scheme covers the whole Dutch population. Therefore, we use the demographic data provided by CBS (*Centraal Bureau voor de Statistick*). This gender specific data set includes the population size and the survival probabilities for each cohort and the projection of both for the upcoming years. The model uses the initial population data and generates the size of the population for each cohort in the future using the survival probabilities. For example, the size of male population of age x at time t is calculated as

$$MalePop_t^x = MalePop_{t-1}^{x-1} \times p_{t-1,x-1}^{male}, \tag{1}$$

where $p_{t-1,x-1}^{male}$ is the one-year survival probability of a male of age $x-1$ at year $t-1$.

3. Valuing the embedded options implied by UK pension policies in the multi-period model

3.1. Policies

We start from building an HBS for a basic pension policy, then gradually adding more complexity to the example. This way, we can easily track how each new feature of a pension policy affects the HBS. We call the first policy the baseline policy, as it does not have any steering tools or adjustment mechanisms that are available to the trustees of the pension scheme. The policies are summarised in Table 2. The details of each policy will be introduced when we discuss the results in the following subsections.

Table 2
The pension policies used to build the HBS. The indexation is linked to the price level. "UK" means that the indexation will be capped following UK DB pension indexation rules. "PPF" is a different cap rules for the indexation.

	Price indexation	Recovery plan	Credit risk	PPF guarantee
Policy 1	full	–	–	–
Policy 2	UK	–	–	–
Policy 3	UK	Recovery plan	–	–
Policy 4	UK	Recovery plan	Credit risk	–
Policy 5	PPF	Recovery plan	Credit risk	PPF guarantee

Table 3
Summary of the HBS for the UK pension policies.

	Policy 1	Policy 2	Policy 3	Policy 4	Policy 5
Pension Assets	117.50	117.50	117.50	117.50	117.50
Sponsor guarantee			14.86	14.36	14.49
PPF guarantee					7.90
PPF levy					−0.52
Total	117.50	117.50	132.36	131.86	139.37
Pension Liabilities	100.00	100.00	100.00	100.00	100.00
Indexation	32.28	21.95	21.95	21.95	21.50
PPF cut					−1.13
Residue	−14.78	−4.45	10.41	9.91	19.00
Surplus option	16.69	20.33	22.45	22.36	22.80
Deficit option	−31.47	−24.78	−12.04	−12.45	−3.80
Total	117.50	117.50	132.36	131.86	139.37

The HBS for each of the policies is presented in Table 3. The pension assets on the HBS have the value of the pension asset portfolio and the pension liabilities equal the present value of the total benefits. These are the same as the assets and the liabilities in the traditional balance sheet. The pension scheme has a funding ratio of 1.175, which results from the pension assets divided by the pension liabilities. This is the initial funding ratio we set in our value-based ALM model. We choose 1.175 as the initial funding ratio for the UK pension policies because we want to compare the HBS of the UK pension policies with the Dutch ones, and 1.175 is the solvency funding ratio required by the Dutch regulator. In later sections, we will change the initial funding to different levels in the sensitivity analysis.

3.1.1. The HBS for Policy 1 (baseline)

Policy 1 gives full indexation to the benefits and the indexation is linked to the price level. The amount of indexation is path dependent. From the risk-neutral scenario set, we know the actual indexation materialised, thus, we can calculate the resulting increased benefits. Taking average of all these increased benefits and discounting to the present using the path dependent risk-free rate will return the value of this indexation option. The calculation can be expressed as

$$V_0^{ind} = E_0^{\mathbb{Q}}\left[\sum_{t=1}^{15} ind_t \cdot B_t \cdot \prod_{k=0}^{t} \frac{1}{1+r_{f,k}}\right], \tag{2}$$

where V_0^{ind} is the value of the indexation option at time 0, ind_t is the indexation given at time t, B_t is the total benefits participants are entitled to at time t, and $r_{f,k}$ is the annual risk free rate in year k.

From Table 3,[3] we can see that full indexation is a very expensive policy for the pension scheme. It increases the total liability by 32.28 and will worsen the funding position of the pension scheme in the future.

The last option on the HBS for Policy 1 is the residue option. Residue is the difference between assets and liabilities of the pension fund at the end of each scenario path. In this closed fund setting, the residue represents the value of surplus/deficit that the pension scheme has at the end of our investigation (15 years). Thus, the deficit option is a bad result for participants, i.e. there are not enough assets to cover the promised benefits.

The value of the residue option is calculated the same way as the indexation option. The pension surplus/deficit for each scenario at year 15 is discounted to present using the risk-free interest rates of each scenario path, then the average is taken to give the residue option value. The expression to calculate the residue option can be written as

$$V_0^{RO} = E_0^{\mathbb{Q}}\left[(A_T - L_T)\cdot\prod_{k=0}^{T}\frac{1}{1+r_{f,k}}\right], \tag{3}$$

where V_0^{RO} is the value of the residue option, T is the time the pension scheme is liquidated, A_T and L_T are the pension assets and liabilities at T, respectively. We can also take the average of the surplus and the deficit respectively, thus disintegrating the residue option into a surplus option and a deficit option. This way, we can have an idea of how the residue option is divided between surplus and deficit, and track the impact when we introduce new pension policies. Policy 1's deficit option has a value almost double the value of its surplus option, leaving the total residue option of a value of −14.78. This is not a good news for participants, as there are chances that the promised benefits may not be fulfilled by the pension scheme when it is liquidated.

The whole set of pension options can be seen as a zero-sum game. The value transferred between stakeholders through one option will appear up in other options transferred in the opposite direction. The high value of the indexation option due to the full indexation guarantee is counterbalanced by the negative value of residue option, bringing both sides of the HBS in balance.

3.1.2. The HBS for Policy 2 (UK indexation rules)

Now, the pension scheme is switched from Policy 1 to Policy 2. The indexation follows the UK indexation rules. The indexation is linked to the price level but capped at 5% for the pensions in payment and 2.5% for the deferred pensions. Policy 2 is worse for participants than Policy 1, as it gives less benefits than Policy 1 if the price level is higher than the capped level. This is reflected in the HBS (Table 3). The indexation option now has the value of 21.95 as compared to 32.28 in Policy 1. The funding position is improved with the restrain on indexation as can be shown with a less negative value of the residue option. The less negative residue option can be explained by a more positive surplus option and a less negative deficit option compared to Policy 1, with the reduction in deficit contributing the most to the improvement of the residue option value.

[3] The value-based ALM model returns the values of assets and liabilities as well as the options in Euro amount. To aid comparison between policies and help understanding the results, each value on the HBS is normalised to the value of the pension liabilities, and then times 100. For example, if the pension assets have a value of €150 million and the pension liabilities have a value of €120 million, the recalculated values of the pension assets and liabilities on the HBS will be 125 and 100, respectively. One can read from the HBS quickly that the pension scheme has a funding ratio of 1.25. Similarly, an indexation option with the value of €30 million will be shown as 25 on the HBS. Since the value of the pension liabilities is the present value of future benefits, it remains the same for all different policies. Therefore, the relation between the values on different HBSs holds the same in Euro amount.

3.1.3. The HBS for Policy 3 (recovery plan)

The UK Pension Act 2004 states that the pension scheme is subject to the statutory funding objective that the assets of the scheme are sufficient to meet its liabilities. If there is a pension funding shortfall, a recovery plan will be prepared and agreed upon between the sponsor company and the trustees of the scheme. The recovery plan can be such that the sponsor contributes a certain amount of assets to the pension scheme in a span of several years so that by the end of the planned period, the pension funding shortfall will be eliminated. We assume that the recovery contribution should not jeopardise the financial position of the sponsor.

To extend our model and include the recovery plan with the above mentioned features, we make the following assumptions. At the end of each year, after the indexation has been calculated, the pension scheme's funding position will be examined. If there is a funding shortfall, the model initiates a recovery plan. The amount of contributions and the length of the period of the plan will depend on both the size of the pension funding shortfall and the financial position of the sponsor company. If the pension funding shortfall is less than or equal to the sponsor's equity value, the difference between the sponsor's assets value and debts value, a part of the sponsor's assets that equals the pension funding shortfall will be transferred to the pension scheme. In this way, the financial position of the sponsor will not deteriorate severely and the pension funding shortfall can be eliminated quickly.

If the size of the pension funding shortfall is larger than one quarter of the sponsor's equity value, but less than full equity value, the recovery plan will be set up in eight annual instalments with the first instalment equal to 1/8 of the pension funding shortfall. We choose 8 years as the length of the recovery plan because this is the medium length of years of the recovery plan in UK private DB pension schemes. Another situation is that the pension funding shortfall is larger than the full equity value of the sponsor, then the first instalment will be 1/8 of the sponsor equity. These setting allows pension fund to reduce its funding shortfall gradually and reach its "statutory target" in the future but does not put the sponsor into a stressed situation.

One should note that the recovery plan will be reviewed at each end of the year, i.e. if the conditions change, the recovery plan will be revised accordingly. We express the recovery contribution at a certain time t as

$$C_t^{rec} = \begin{cases} L_t - A_t & \text{if } 0 < L_t - A_t \le \dfrac{1}{4}(S_t - D_t) \\ \dfrac{1}{8}(L_t - A_t) & \\ \quad \text{if } 0 < \dfrac{1}{4}(S_t - D_t) < L_t - A_t \le (S_t - D_t) & \\ \dfrac{1}{8}(S_t - D_t) & \text{if } 0 < S_t - D_t \le L_t - A_t \\ 0 & \text{otherwise,} \end{cases} \tag{4}$$

where C_t^{rec} is the recovery contribution, A_t is the pension assets, L_t is the pension liabilities, S_t is the sponsor assets, and D_t is the sponsor debts. The model records the actual amount of the contributions the sponsor pays each year and then calculates the value of the sponsor guarantee option in this way:

$$V_0^{rec} = E_0^{\mathbb{Q}}\left[\sum_{t=0}^{15} C_t^{rec}\prod_{k=0}^{t}\frac{1}{1+r_{f,k}}\right]. \tag{5}$$

In the value-based ALM model, part of the assets value is transferred from the sponsor to the pension scheme. Therefore, we need to know the sponsor's assets and debts in absolute Euro amount. As the purpose is to show how this recovery contribution affects the HBS, for now, we assume that the initial sponsor's assets is 1.5 times of the initial pension assets and the level of the sponsor's

debts is 30% of the level of the sponsor's assets. In addition, there will be scenarios that the sponsor's asset level is below its debts level. If we do not allow the sponsor to become insolvent (for example, a public organisation), we can assume the sponsor is still running as a going concern but cannot afford to contribute to the recovery plan until its asset level returns to above its debt level.

In the value-based ALM model, the options are valued in the risk neutral measure $\mathbb{Q}$. The model involves time-variant volatilities and shocks that represent sudden financial market collapses such as the 2008 event. It generates scenarios that give the values of relevant risk factors such as stock returns, bond returns, and inflations. The evolution of the pension assets and liabilities can then be simulated.

We simulate the evolution of the sponsor assets and debts in a similar manner as the pension assets and liabilities. We assume that the sponsor's asset portfolio consists of stocks and bonds which is different in proportion from the pension asset portfolio. If a portfolio of 100% stocks represents the market risk, to reflect the idiosyncratic risk inherent in the individual company, the sponsor asset portfolio is assumed to have 110% in stocks and −10% in bonds. We assume that the sponsor debts evolves in the same way as a risk-free asset, thus, it grows according to the risk-free rates in the scenario set, which are the Euribor rates. The evolution of the sponsor assets S_t and debts D_t at the beginning of the year t can be written as

$$S_t = \alpha_S S_{t-1}(1 + r_t^S) + (1 - \alpha_S) S_{t-1}(1 + r_t^B), \tag{6}$$

$$D_t = D_{t-1}(1 + r_t) \tag{7}$$

where α_S is the proportion of the sponsor asset portfolio which is invested in stocks (110% in this example), r_t^S is the annual stock return, r_t^B is the annual bond return, and r_t is the risk-free rate.

The HBS for Policy 3 is shown in Table 3. We call the option that the sponsor pays recovery contributions the sponsor guarantee option. This option is the additional assets the pension scheme will receive from its sponsor in case of the pension funding shortfall. Therefore, it appears on the assets side of the HBS and increases the total assets by 14.86.

The residue option now has a positive value and it balances both sides of the HBS. One can also see that the surplus option has a higher positive value and the deficit option has a lower negative value compared to Policy 2. We do not assume who will receive the pension funding surplus when the pension scheme is liquidated at the end of year 15. One may suggest that part of the surplus is returned to the sponsor to compensate its contribution to the recovery of pension funding shortfalls.

Another issue regarding the residue option is that when the pension is liquidated after 15 years, if the pension scheme has a funding shortfall, the sponsor may not pay the recovery contribution that equals the full size of the shortfall according to Eq. (4). If the sponsor will eventually guarantee all the funding shortfall after the scheme is liquidated, the residue option will have a higher positive value. Pension participants will end up with only good situations (potential surplus and no downside risk).

3.1.4. The HBS for Policy 4 (credit risk)

The Merton model. Based on Policy 3, we introduce the credit risk to the model and form Policy 4 for the pension scheme. We model the insolvency event based on the Merton model of credit risk. The company's capital structure consists of debt and equity. The model assumes that the company does not pay coupons on its debt or dividends on its equity. The Merton model treats a company's equity as a European call option on its assets with the strike price of the face value of the company's debt and the maturity of the time the debt is due. If the total asset at the maturity date has a value less than the debt, the option is out of the money—equity holders does not get anything from the company. We define the insolvency event in our model as the total value of the sponsor's assets less than the total value of the sponsor's debts. This allows us to calculate the insolvent probability and simulate insolvency events.

The assumptions about the evolution of the sponsor assets and debts are the same as in Policy 3. But if the sponsor's asset level becomes less than its debt level, the sponsor will be insolvent and remains so afterwards. For the pension scheme, this means that the sponsor can only contribute to the recovery plan as long as it is solvent. If the sponsor becomes insolvent, the pension scheme will operate independently until it is liquidated at year 15.

The HBS for Policy 4 is presented in Table 3. As expected, the value of the sponsor guarantee option is lower than in Policy 3. This is because the insolvent sponsor no longer contributes to the recovery plan. This reduces the value of this conditional asset. Correspondingly, the residue option has a less positive value than in Policy 3. Participants have a worse contract than policy 3.

One may notice that the reduction in the value of the sponsor guarantee option by introducing the credit risk is very small (14.36 in Policy 4 as compared to 14.86 in Policy 3). This is due to our assumption of how the sponsor pays the recovery contributions and the choice of the asset portfolios of the pension scheme and the sponsor company. In Policy 3, the sponsor can have a negative equity value and remains a going concern. We assume that the sponsor with a negative equity will not pay any contributions to the recovery plan. In addition, the pension scheme has 50% assets in stock and the sponsor has 110% assets, thus, the pension scheme and the sponsor company tend to be in deficit at the same time in our scenarios. For these reasons, the sponsor without credit risk and the sponsor with credit risk have very similar contribution cash flows in each scenario path. The sponsor without credit risk has a limited number of extra cash flows when the sponsor recovers from negative equity value. Thus, the credit risk in Policy 4 reduces only a small amount of recovery contribution cash flows, and has a very limited effect on the value of the sponsor guarantee option.

3.1.5. The HBS for Policy 5 (PPF)

Finally, Policy 5 introduces the PPF protection to the pension scheme. The PPF takes over the pension scheme's assets and liabilities if the sponsor becomes insolvent and the pension scheme's assets cannot cover the liabilities guaranteed by the PPF. The PPF policy affects the stakeholders of a pension scheme in multiple ways. The PPF only guarantees part of the liabilities, 100% of the benefits of the pensioners and 90% of the accrued benefits of the active members, subjected to a cap. In addition, the pension scheme needs to pay annual premiums to the PPF until the sponsor becomes insolvent in exchange for the protection.

Like a sponsor, the PPF covers the pension funding shortfall, but only up to a limit. The PPF guarantee option can be perceived as a contract between the PPF and the pension scheme's participants. Participants benefit from the contract when the sponsor becomes insolvent and there is a pension funding shortfall. The size of the payoff depends on the extent of the pension funding shortfall. The PPF guarantee option will have the highest payoff in the worst case scenario, i.e. the insolvent sponsor cannot contribute and the pension fund has a large funding shortfall. The PPF guarantee option appears on the asset side of the HBS as it is a contingent asset. If we denote the liabilities that the PPF guarantees to be L^{PPF}, the payoff the pension scheme will receive when it is taken over by the PPF is $(L_t^{PPF} - A_t^{PPF})_+$. The calculation of the PPF guarantee option can then be expressed as

$$V_0^{PPF} = E_0^{\mathbb{Q}}\left[\sum_{t=0}^{15}\left(L_t^{PPF} - A_t^{PPF}\right)_+ \prod_{k=0}^{t}\frac{1}{1 + r_{f,k}}\right]. \tag{8}$$

On the other hand, participants' entitled benefits are cut once the PPF takes over the pension scheme. The extent of the cut

depends on the status of the individual participant and the cap set by the PPF. There is also another situation that when the sponsor becomes insolvent, the pension assets are larger than the liabilities guaranteed by the PPF. In this case, life insurance contracts are bought which pays off benefits equal to the amount that the remaining pension assets can cover. This is also a cut as participants cannot receive their entitled benefits in full amount. Although the PPF will not take over the pension scheme in this case, the cut is incurred because of the introduction of the PPF protection into the policy. Therefore, we also consider this kind of cut as part of the PPF cut option. One more situation is that there may be more than enough assets in the pension scheme to cover the entitled benefits when the sponsor is insolvent. Instead of considering this surplus as a "negative cut", we categorise it as a residue and include it when we calculate the residue option. The PPF cut can be expressed as

$$Cut_t^{PPF} = \begin{cases} 0 & \text{if } A_t > L_t; \\ A_t - L_t & \text{if } L_t^{PPF} < A_t < L_t; \\ A_t - L_t^{PPF} & \text{if } A_t < L_t^{PPF} < L_t. \end{cases} \tag{9}$$

This cut option is a contract between the PPF and participants and reduces the entitled benefits of participants. Therefore, the value of the PPF cut option appears as a negative value on the liability side of the HBS. The value of the PPF cut option is calculated in the following way:

$$V_0^{cut} = E_0^{\mathbb{Q}}\left[\sum_{t=0}^{15} Cut_t^{PPF} \prod_{k=0}^{t} \frac{1}{1+r_{f,k}}\right]. \tag{10}$$

Participants' losses also include the reduction in indexation. Once in the PPF, the benefits are indexed to the price level capped at 2.5%. This does not affect deferred pensions but the pensions in payment will be less than the UK indexation rules if the price level is above 2.5%.

Like in an insurance contract, the pension scheme also pays premium, called levy, to the PPF annually up till the moment the sponsor becomes insolvent. The amount of the levy depends on multiple factors: the size of the pension scheme's liabilities, the pension scheme's funding position, the credit risk of the sponsor, and the funding position of the PPF itself. Given the above factors, one can calculate the levy according to the formula provided by the PPF (PPF Determination 2013). To avoid diverging from our main results, we present the calculation in Appendix B.1.

The levy charge reduces assets of the pension scheme. The future values of the levy cash flows depend on market conditions. Therefore, we consider the levy as a conditional asset (negative) and present it as an option on the asset side of the HBS. One can view the levy option as an exotic call option the pension scheme writes to the PPF. The payoff depends on the variables in levy valuation formula and the status of the sponsor company. However, the levy charges do not affect the entitled benefits of the pension participants. The value of the levy option is calculated as

$$V_0^{Levy} = E_0^{\mathbb{Q}}\left[\sum_{t=0}^{15} -Levy_t^{PPF} \prod_{k=0}^{t} \frac{1}{1+r_{f,k}}\right]. \tag{11}$$

Table 3 presents the HBS for Policy 5. From the HBS, introducing the PPF protection to the pension policy appears to be a good deal for participants. The PPF guarantee option has a value of 7.9. The PPF takes the position of the sponsor after the sponsor becomes insolvent, and guarantees most of the benefits participants are entitled to. The losses participants need to bear due to the reduction in indexation is very limited: only a reduction of 0.45 in the indexation option value compared with Policy 4. The PPF cut option has a value of −1.13, a relative small amount compared with the PPF guarantee option.

Although this paper does not address whether the PPF itself will be sustainable given its current policies, we find in our multi-period model that the *ex post* value of the PPF guarantee option provided by the PPF to the pension scheme is considerably more than the *ex post* value of the levy option that the PPF charges from the pension scheme. Ideally, the premium would be at a similar level of the expectation of the payoff from an insurance contract. On the HBS, the big difference between the values of the PPF guarantee option and the PPF levy option appears to be a good contract for the pension scheme and its participants. What might contribute to the difference? One cause can be the discrepancy in the model used to simulate the PPF levy charges and the model used to simulate the PPF guarantee payoffs. The PPF levy charges are calculated based on the parameters in the PPF formula (see Appendix B.1), which in turn are the results from the internal stochastic model of the PPF. However, the payoff of the PPF guarantee are simulated under our model.

In addition, our model uses economic scenarios that are generated from financial data in 2011, when low investment returns complicated with high volatility were observed. This leads to a high frequency of sponsor insolvency and low and volatile asset returns in our model, which in turn increases the PPF guarantee option value and reduces the levy needs to be paid.

Overall, introducing the PPF protection increases the residue option value, mainly resulting from reduced value of the deficit option. We can conclude that the PPF protection is a good pension deal for participants as it eliminates some of the downside risk if the sponsor becomes insolvent and the pension scheme has a funding shortfall.

3.2. Sensitivity analysis

The HBS for the UK pension policies are built under various assumptions including the pension scheme's initial funding position, the investment strategy of the pension scheme, the sponsor's size and leverage ratio, etc. Changing the initial assumptions will affect the values of the contingent claims on the HBS. Therefore, it is crucial to understand how the HBS behaves once the assumptions are adjusted to various situations. In this section, we present a sensitivity analysis of the HBS for the UK policy. By modifying one of the assumptions and keeping the others unchanged, we can have a general picture of how sensitive the option values are to the specific variable modified.

Policy 5 includes the sponsor guarantee, sponsor's credit risk, and the PPF protection. This represents most of the instruments available to a UK DB pension scheme. Therefore, we choose Policy 5 to conduct the sensitivity analysis. We call Policy 5 the benchmark and the assumptions are

1. The sponsor has an initial leverage ratio of 30%, i.e. the total debts is 30% of the total assets.
2. The sponsor's initial asset level is 1.5 times of the pension scheme's.
3. The pension scheme has the initial funding ratio of 1.175.
4. The pension scheme invests 50% of its assets in stocks and 50% in bonds.
5. The sponsor invests 110% of its assets in stocks and −10% in bonds.

We modify each one of the assumptions and keep the rest unchanged. The HBS under the new assumptions are compared for the sensitivity analysis. The results of the sensitivity analysis can be found in Chen (2013). Table 4 provides a review of how the value of the embedded options will change if an initial assumption is modified.

4. Valuing the embedded option implied by Dutch pension policies in the multi-period model

In the previous section, we valued the embedded option of pension contracts and constructed the holistic balance sheet. The HBS

Table 4
Summary of the sensitivity analysis for the UK policy (Policy 5). The table presents the directions of change in the value of embedded options after an assumption is modified. D_0/S_0 is the initial leverage ratio, S_0/A_0 is the relative size of the initial sponsor's assets and the initial pension's assets, α_S is the proportion of the sponsor's assets invested in stocks, ifr represents the initial funding ratio of the pension scheme and α_A is the proportion of the pension's assets invested in stocks.

	$D_0/S_0\uparrow$	$S_0/A_0\uparrow$	$\alpha_S\uparrow$	ifr $\uparrow$	$\alpha_A\uparrow$
Pension Assets	–	–	–	↑	–
Sponsor guarantee	↓	↑	↓	↓	↑
PPF guarantee	mix	↓	↑	↓	↑
PPF levy[a]	mix	↑	mix	↑	↓
Total	↓	↑	↓	↑	↑
Pension Liabilities	–	–	–	–	–
UK indexation	↓	↑	↓	↑	↓
PPF cut[a]	↓	↑	↓	↑	↓
Residue	mix	↑	↓	↑	↑
Surplus option	↓	↑	↓	↑	↑
Deficit option[a]	↑	↑	↓	↑	↓
Total	↓	↑	↓	↑	↑

[a] The PPF levy, the PPF cut and the deficit option have negative values. Up means the values become less negative and down more negative.

allows us to study the value transferred between the stakeholders of the pension scheme as a result of introducing a new policy feature. We can use the HBS approach as a quantitative tool to compare different pension policies. In this section, we first build an HBS for the pension policies with typical Dutch steering tools and adjustment mechanisms, namely the sponsor guarantee contribution, the conditional indexation, and recovery contribution. Like for the UK policies, we add each one of the features and build the HBS step by step and conduct the sensitivity analysis.

The aim is to compare policies from UK and the Netherlands, thus, we keep the assumptions about the pension scheme, the demographic composition, and the survival probabilities the same as in the previous section. The only difference is what kind of tools are available to the scheme's trustees.

4.1. Policies

The Dutch policies we will build the HBS for are summarised in Table 5. We keep Policy 1 from the previous section as our baseline policy. The characteristic of each new steering tools and adjustment mechanism will be explained in detail when we present the results.

The HBS for each of the policies are presented in Table 6. Note that Dutch DB pension schemes link indexation to average wage growth, whereas in the baseline policy, we employ the UK indexation linked to the price level. We will keep to link the indexation to the price level for the Dutch policies in this section, so that our comparison of UK and Dutch policies are not influenced by the differences of price and wage levels.

4.1.1. The HBS for Policy 6 (conditional indexation)

To maintain a healthy funding ratio, Dutch pension schemes can employ a conditional indexation policy. How much indexation is given to participants depends on the actual funding ratio. If the funding ratio is above the predetermined cap, the full indexation is given. There is also a floor under which if the funding ratio falls, no indexation will be given. If the funding ratio is between the floor and the cap, only a proportion of the full indexation is given. The proportion equals the ratio of the difference between the funding ratio and the floor to the difference between the cap and the floor. We can express the conditional indexation as:

$$I_t^c = \begin{cases} I_t^f & \text{if } C < FR_t; \\ \dfrac{FR_t - F}{C - F} \cdot I_t^f & \text{if } F < FR_t < C; \\ 0 & \text{if } FR_t < F, \end{cases} \tag{12}$$

where C and F are the cap and floor, respectively, I_t^f is the full indexation at time t, I_t^c the conditional indexation, and FR_t the funding ratio. In the model, the floor and the cap are set at 1.05 and 1.30, respectively. By giving conditional indexation, the pension scheme avoids being too generous and can recover from a low funding ratio quickly.

The results of the HBS for Policy 6 are presented in Table 6. The value of the conditional indexation option is only 1/3 of that of the full indexation option in the HBS of Policy 1. This greatly improves the funding status of the pension scheme, as the residue option value increases from −14.78 to 6.76. This is partly due to the increase in the value of the surplus option but mostly because of the reduction in the negative value of the deficit option. From participants' perspective, the conditional indexation is a worse contract than the full indexation. However, just because of the sacrifice participants make when the funding ratio is low, there is a higher probability that a funding surplus is left when the scheme is liquidated.

4.1.2. The HBS for Policy 7 (sponsor support)

Now, we introduce the sponsor support to form Policy 7. The sponsor support in a Dutch pension policy can be compared with the recovery plan in a UK pension policy. In both cases, the sponsor pays contributions to improve the pension scheme's funding position. Instead of paying to diminish the pension funding shortfall over a span of years, the sponsor of a Dutch pension scheme is obliged to make up the difference as soon as the funding ratio is below a certain level. We call this critical level the guaranteed funding ratio FR^g. To model the sponsor support contributions, we need to take into account if the sponsor can afford the payment. There is a chance that the amount of the contribution to recover the funding ratio to the guaranteed level is so big, that the sponsor cannot afford to pay or will be in a stressed situation after the payment. To avoid these situations, we set up rules so that the amount a sponsor contributes in a year can never exceed one quarter of its equity. We express the contribution as

$$C_t^{sup} = \begin{cases} (FR^g - FR_t) \cdot B_t \\ \quad \text{if } 0 < (FR^g - FR_t) \cdot B_t \le \dfrac{1}{4}(S_t - D_t) \\ \dfrac{1}{4}(S_t - D_t) \\ \quad \text{if } 0 < \dfrac{1}{4}(S_t - D_t) < (FR^g - FR_t) \cdot B_t \\ 0 \quad \text{otherwise}, \end{cases} \tag{13}$$

where C_t^{sup} is the contribution payment of the sponsor support, B_t the total benefits, S_t the sponsor's assets and D_t the sponsor's debts. Our model assumes FR^g to be 0.96. Like for Policy 3, the model for Policy 7 assumes no credit risk of the sponsor. The sponsor is still running as a going concern with a negative equity value and it will only contribute to the sponsor support when its equity is in the positive territory.

The HBS is presented in Table 6. The sponsor support option is a conditional asset and is presented on the asset side of the HBS. The sponsor support option has a value of 10.67, improving the HBS. This contract is a good deal for participants not only for there is additional contributions from the sponsor when the funding ratio is low, and also for it increases the value of the indexation option. When the sponsor guarantees part of the funding shortfalls,

Table 5
The pension policies with Dutch tools.

	Price indexation	Sponsor support	Credit risk	Employee contribution
Policy 1	full	–	–	–
Policy 6	Conditional	–	–	–
Policy 7	Conditional	Sponsor support	–	–
Policy 8	Conditional	Sponsor support	Credit risk	–
Policy 9	Conditional	Sponsor support	Credit risk	Employee contribution

Table 6
Summary of the HBS for the Dutch pension policies.

	Policy 1	Policy 6	Policy 7	Policy 8	Policy 9
Pension Assets	117.50	117.50	117.50	117.50	117.50
Sponsor support			10.67	10.27	7.60
Total	117.50	117.50	128.17	127.77	125.10
Pension Liabilities	100.00	100.00	100.00	100.00	100.00
Indexation	32.28	10.74	11.59	11.58	12.35
Sustainability cut					−12.40
Residue	−14.78	6.76	16.58	16.19	25.15
Surplus option	16.69	18.27	22.32	22.22	25.32
Deficit option	−31.47	−11.51	5.74	−6.03	−0.17
Total	117.50	117.50	128.17	127.77	125.10

the funding ratio can recover more quickly than without such a support. As a result, participants are more likely to receive higher indexation. Intuitively, the sponsor support policy decreases the value of the deficit option compared with Policy 6, i.e. participants are partially protected from pension underfunding. Thus, the value of the total residue option is increased by 130% to 16.58.

4.1.3. The HBS for Policy 8 (credit risk)

Policy 8 introduces the credit risk of the sponsor. No contributions can be received any longer once the sponsor becomes insolvent. The HBS is presented in Table 6. As one can imagine, the assumption of credit risk will reduce the value of the sponsor support option. However, the reduction is limited to a small extent (<4%). The reason is the same as in Policy 4 when we introduced the credit risk to the UK policy. Given our assumptions of how the sponsor insolvency is modelled, the cash flows of the sponsor support when there is credit risk differs very slightly from that in the case of no credit risk. For the same reason, the values of the conditional indexation and the residue options do not change much.

4.1.4. The HBS for Policy 9 (sustainability cut)

In UK, the PPF plays an important role in protecting most part of the benefits participants are entitled to if the sponsor becomes insolvent. On the other hand, the indexation of participants are guaranteed up to a certain cap depending on the status of the individuals. If these contracts can be fulfilled, the biggest loss participants will bear is the cut of benefits imposed by the PPF if the PPF takes over the scheme.

In comparison, participants in Dutch schemes do not enjoy the protection if the sponsor is insolvent and there is a pension funding shortfall. In addition, the indexation can be conditional on the funding ratio. Some contract even requires the participant to sacrifice so that the funding ratio will return a certain level. Policy 9 will address this issue and introduce the so-called sustainability cut contract.

As the name suggests, the sustainability cut allows the benefits to be cut to ensure the sustainability of the scheme. The cut is through a negative indexation of the benefits. Once the funding ratio falls below a critical level, the floor, the sustainability cut contract is initiated and a plan to recover the funding ratio to be at least at the floor level is set up. To avoid abrupt losses to participants and the resulting unfairness across generations,[4] the sustainability cut is executed across a few years. There is an equal step of increase in the funding ratio in each year which the pension scheme needs to achieve. If not, the benefits will be cut so that funding ratio will reach the required milestone in that particular year. After all the cuts and the asset returns are taken into account, the funding ratio should be at least at the floor level at the end of the planned period.

Policy 9 sets the floor at 1.05 and the length of the sustainability cut to be 3 years. We give an example of how the plan can be set up. Suppose the funding ratio is 0.99 now and it is the first time that the funding ratio is below 1.05. According to the rules above mentioned, each year the funding ratio needs to increase at least $(1.05 - 0.99)/3 = 0.02$. Thus, the milestones for the funding ratio to recover to in the next three years will be 1.01, 1.03, and 1.05. If the funding ratio at the end of the first year turns out to be 1, the benefits will be cut. A negative indexation is then given as $1/1.01 - 1 = -0.0099$. Multiply this indexation by the total benefits will give how much cut participants have to bear at the end of the first year. The same procedure is practised each year till the end of the plan.

One more assumption we make in Policy 9 is that the sponsor support is exercised before the sustainability cut. For example, if the funding ratio falls down to below 0.96, the level sponsor will guarantee up to, the sponsor will pay the contribution first so that the funding ratio recovers to 0.96. Then the sustainability cut is initiated, and a plan with milestones of 0.99, 1.02, and 1.05 for each of the next three years is set up.

The HBS is presented in Table 6. The value of the sustainability support is calculated in the same way as the indexation option. Since it is a cut of the benefits, the sustainability cut appears a negative figure on the liability side of the HBS. In our results, this option has a value of −12.40. Introducing the sustainability cut also reduces the conditional assets. The sustainability cut contract alleviates the burden on the sponsor, as the sponsor guarantee option has a value 26% less than that in Policy 8. Furthermore, the value of the deficit option is close to 0, resulting in a higher total residue option value.

The value of the sustainability cut option and that of the conditional indexation option have the same magnitude. One should notice that they have different economic values to the pension scheme. The sustainability cut is employed in the bad scenarios. The negative indexation is vital to the solvency of the pension scheme. On the contrary, the conditional indexation is given when the funding ratio is above the critical floor level. Therefore, the sustainability cut has a more economic value to the pension scheme than the conditional indexation.

From Table 6, one can review the impact of each new feature on the value of embedded options. We observe that the sponsor support benefits participants and improves the funding position. Participants sacrifice through the sustainability cut, which reduces part of the sponsor's obligation.

[4] The pensioners suffer from less income. Younger generations has less accrued benefits and they have longer time to wait and may gain back the loss finally if there is the catch-up indexation policy. For older generations, the chance to gain back through such policy will be lower.

Table 7
Summary of the sensitivity analysis for the Dutch policy (Policy 9). The table presents the directions of change in the value of embedded options after an assumption is modified. D_0/S_0 is the initial leverage ratio, S_0/A_0 is the relative size of the initial sponsor's assets and the initial pension's assets, α_S is the proportion of the sponsor's assets invested in stocks, ifr represents the initial funding ratio of the pension scheme and α_A is the proportion of the pension's assets invested in stocks.

	$D_0/S_0\uparrow$	$S_0/A_0\uparrow$	$\alpha_S\uparrow$	ifr $\uparrow$	$\alpha_A\uparrow$
Pension Assets	–	–	–	↑	–
Sponsor support	↓	↑	↓	↓	↑
Total	↓	↑	↓	↑	↑
Pension Liabilities	–	–	–	–	–
Conditional indexation	↓ (limited)	↑ (limited)	↓(limited)	↑	↓(limited)
Sustainability cut[a]	↓	↑ (limited)	↓	↑	↓
Residue	↓ (limited)	↑ (limited)	↓(limited)	↑	↑
Surplus option	↓ (limited)	↑ (limited)	↓(limited)	↑	↑
Deficit option[a]	↓ (limited)	↑ (limited)	↓(limited)	↑	↓(limited)
Total	↓	↑	↓	↑	↑

[a] The sustainability cut and the deficit option have negative values. Up means the values become less negative and down more negative.

4.2. Sensitivity analysis

Policy 9 is selected for the sensitivity analysis, as it contains typical policy instruments of a Dutch DB pension scheme. We make the following assumptions for Policy 9:

1. The sponsor has an initial leverage ratio of 30%, i.e. the total debts are 30% of the total assets.
2. The initial sponsor's asset level is 1.5 times of that of the pension scheme's.
3. The pension scheme has the initial funding ratio of 1.175.
4. The pension scheme invests 50% of its assets in stocks and 50% in bonds.
5. The sponsor invests 110% of its assets in stocks and −10% in bonds.

We modify each one of the assumptions and keep the rest unchanged. The effect on the HBS is then examined and the results are discussed in detail by Chen (2013).

Table 7 summarises how the values of the embedded options will change when an initial assumption is adjusted. From the table, we note that the adjustment of each one of the assumptions mainly impacts the value of the sponsor support option and the sustainability cut option. The Dutch policy focuses on maintaining a healthy funding position. The burden of keeping the funding ratio above a target minimum level is born on both the sponsor and participants. Any adjustment in the assumptions that harms the sponsor's ability to contribute will result in an increase in the benefit cuts participants need to sacrifice. Both the sponsor and participants will benefit from an improved funding ratio such as an increase in the initial funding ratio, so that the sponsor support contributions and benefit cuts will be reduced (in absolute term).

We also notice that changes in most of the assumptions, apart from the initial funding ratio, have limited effect on the value of the conditional indexation and the deficit option. The conditional indexation is linked to the funding ratio and it gives no indexation when the funding ratio is lower than the minimum target and gives full indexation only when the funding ratio is above a certain high level. The downside risk of low funding ratio has already been taken by the sponsor and participants through the sponsor support and the sustainability cut. None of these assumptions, apart from the initial funding ratio, has an influence on the funding ratio above the minimum target level. Hence we observe limited impact of the changes in these assumption on the value of the conditional indexation option. For a similar reason, the impact on the value of the deficit option is also limited.

Table 8
The HBS of Policy 5 (UK) and Policy 9 (NL).

	Policy 5	Policy 9
Pension Assets	117.50	117.50
Sponsor guarantee/support	14.49	7.60
PPF guarantee	7.90	
PPF levy	−0.52	
Total	139.37	125.10
Pension Liabilities	100.00	100.00
Indexation	21.50	12.35
Sustainability cut		−12.40
PPF cut	−1.13	
Residue	19.00	25.15
Surplus option	22.80	25.32
Deficit option	−3.80	−0.17
Total	139.37	125.10

5. Comparison of the typical UK and Dutch policies

Policy 5 and Policy 9 include typical tools available to DB pension schemes in UK and the Netherlands, respectively. Now, we present results of Policy 5 and Policy 9 side by side, so that the policy instruments from UK and the Netherlands can be compared.

The first impression of Table 8 is that Policy 5 has higher values (12% more in total) of the conditional assets and the conditional liabilities. Both policies provide recovery contributions from the sponsor, whereas the value of the sponsor guarantee option in Policy 5 almost doubles the value of the sponsor support in Policy 9. This is partly because Policy 5 sets up a goal of full recovery (funding ratio of 1), whereas Policy 9 targets a funding ratio of 0.96, and partly because contributions from participants through the sustainability cut in Policy 9 help reduce sponsor's obligations.

In addition, Policy 5 contains an extra protection instrument for participants, the PPF guarantee, which insures a big proportion of the benefits if the sponsor becomes insolvent. All of these contribute to a higher level of total assets on the HBS of Policy 5.

Besides, Policy 5 has a more generous indexation policy than Policy 9, 74% higher in the value of the indexation option. The indexation in Policy 5 is the minimum of the price level and 2.5% (5% for the pensions in payment) but the indexation in Policy 9 depends on the funding ratio. The impact on participants of Policy

9 is further complicated by the negative indexation through the sustainability cut contract. The aggregate value of the both positive and negative indexation options is close to 0 for Policy 9 versus 21.5 in Policy 5.

In exchange of the PPF protection, the pension scheme in Policy 5 bears the cost of the PPF levy, and participants endures benefit cut. However, the values of the PPF levy option and the PPF cut option are considerably less than the value of the PPF guarantee option. The PPF protection seems to be a good deal for the pension scheme.

The steering tools available to both Policy 5 and Policy 9 result in high surplus option values and low deficit option values in the absolute term. Thus, the total values of the residue options of both policy are high, 19.00 for Policy 5 and 25.15 for Policy 9.

However, the figure itself does not tell us whether a policy is a good or bad deal for the stakeholders of the pension scheme, as manifested by the residue option. If we consider the pension deals as a zero-sum game, one's gain will be at the expense of the others. Therefore, the judgement of a policy should be from the prospective of a particular interest group.

Participants

Based on our analysis, Policy 5 is a better deal for participants than Policy 9. In Policy 5, participants receive a higher indexation, and the pension funding shortfall is guaranteed between the sponsor and the PPF. The benefits are never cut unless the sponsor becomes insolvent and the PPF takes over the scheme. Even so, the losses participants bear are to a limited extent. On the contrary, in Policy 9, participants receive less indexation conditional on the funding position, bear benefit cuts to contribute to the scheme's recovery, and do not enjoy any protection if the sponsor becomes insolvent.

Sponsor

As seen in Table 8, the sponsor of Policy 5 clearly bears a heavier burden than the sponsor of Policy 9. The sponsor of Policy 5 is the only one who contributes to the recovery of funding shortfalls given it is still solvent, whereas the sponsor of Policy 9 shares the obligation with participants. The sponsor guarantee, as a liability, worsens the sponsor's financial situation and increases the insolvent probability. Thus, Policy 5 is a worse contract from the sponsor's perspective than Policy 9.

PPF

Since this section compares Policy 5 and Policy 9 and there is no PPF protection deal in Policy 9, we leave our comments on the PPF in the section of general discussion.

The main difference between Policy 5 and Policy 9 may be the different priorities of the pension schemes. Both schemes aim to have enough assets to cover the liabilities. Policy 5 focuses on the guarantee of participants benefits. On the other hand, Policy 9 targets to maintain a healthy funding ratio.

Before we draw some conclusions, one should note that there are some other adjustment tools available to Dutch pension schemes, such as the catch up indexation. These instruments are in line with the priority of the Dutch schemes to maintain a sustainable funding ratio and give the scheme's trustees more flexibility in the trade off between the indexation and the funding position.

6. Conclusion

The holistic balance sheet, as a quantitative tool, does allow us to evaluate pension policies with different features. Comparing the HBS for typical private defined benefit pension policies from both UK and the Netherlands, we conclude that the UK policy is a better deal for participants, but a worse deal for the sponsor, compared with the Dutch policy.

The UK policy is more generous in giving indexation of the benefits. Potential funding shortfalls are guaranteed by the sponsor. Additionally, the Pension Protection Fund underwrites the credit risk of the sponsor. Therefore, participants of a pension scheme with UK policy bear limited risks of losses of their entitled benefits.

In contrast, the Dutch policy gives indexation that depends on the actual funding ratio of the pension scheme. Participants and the sponsor share the burden of recovery contributions. There is no protection of the benefits if the sponsor is insolvent.

For the sponsor, the UK policy imposes a heavier burden than the Dutch one. In addition, the UK policy is less flexible for the scheme's trustees to choose the steering tools and adjustment mechanisms.

To fully evaluate the impact of adopting the UK policy, one should also take into account the PPF. Whether the PPF is sustainable? Is the structure of the levy charges fair? How to minimise the cross-subsidies between schemes? These are important questions to be addressed.

Appendix A. Value-based ALM model

A.1. Core model

The model starts with the determination of the initial pension assets and liabilities. The initial pension assets (A_0) are calculated as the product of the initial pension liabilities (L_0) and initial funding ratio (FR_0). The pension liabilities is the present value of the total accrued benefit claims. The initial funding ratio is predetermined before running the model. The calculation of the initial pension assets can be expressed as

$$A_0 = L_0 \times FR_0. \tag{14}$$

The value-based ALM model uses a scenario set generated by a risk model that will be explained later. The scenario set contains 5000 scenarios representing possible future economic developments. We assume that full indexations have been granted up till the beginning of the model. Therefore, the accrued benefits for a certain age groups are the same for each of the 5000 scenarios. Since we assume that all the members earn equal annual salaries and the benefits are accrued at 2% of the annual salary, the total accrued benefits for a member would be the annual salary multiplied by the years the member has worked and the 2% accrual rate. We can express the accrued benefit matrix as

$$B_0 = \begin{bmatrix} 0 & 0.02 & 0.04 & \cdots & 0.8 & \cdots & 0.8 \\ \vdots & \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ 0 & 0.02 & 0.04 & \cdots & 0.8 & \cdots & 0.8 \end{bmatrix} \times (5000 \times 75). \tag{15}$$

Each row of the matrix is one of the 5000 scenarios and the columns represent age groups from 25 (no accrued benefits yet) to 99 (accrued to 80% of the average salary). Multiply this matrix with the average wage level and the population for each cohort will give us the total accrued benefits of each age group in each scenario.

To calculate the initial liabilities, each element in the benefit matrix is multiplied by an appropriate discount factor. The discount factor is gender-, cohort-, and scenario-specific. It takes into account the survival probability and discount all the future benefit payments according to the present term structure generated from the scenario set. For example, in a certain scenario s, the discount factor for a male member aged x at time t can be calculated as

$$D^x_{t,s} = \sum_{i=max(65-x,0)}^{99-x} p^m_x(i|t)(1 + R^{(i)}_{t,s})^{-i}, \tag{16}$$

where $p_x^m(i|t)$ is the probability that the male aged x at time t will survive to year i, and $R_{t,s}^{(i)}$ denotes the rate with maturity of i from the nominal term structure at time t in the scenario s. We can view this equation as to calculate a deferred annuity product that pays out benefits until a person deceases. We form the discount factor matrix with elements (16). Each row is one of the 5000 scenarios and each column represents an age group. The discount factor matrix thus has the following form.

$$D_t = \begin{bmatrix} D_{t,1}^{25} & \cdots & D_{t,1}^{99} \\ \vdots & \ddots & \vdots \\ D_{t,5000}^{25} & \cdots & D_{t,5000}^{99} \end{bmatrix} (5000 \times 75). \tag{17}$$

Matrices (15) and (17) are multiplied element-wise, and then each row of the results is summed up to obtain the total liabilities of the pension scheme in a certain scenario. With the initial liabilities, the initial pension assets are calculated according to Eq. (14).

After determining the initial assets, the model starts running. The benefits are paid out to the pensioners at the beginning of each year, and the total amount of the benefits is subtracted from the assets. The remaining assets are then invested according to the predetermined investment strategy and at the end of the year the assets are updated with investment returns generated from the scenario set.

At the end of the year, a new term structure is determined. The pension scheme's liabilities are updated by multiplying the accrued benefit matrix, which takes into account the demographic change, and the discount matrix. The funding ratio at the end of the year is calculated as the ratio of total assets and total liabilities. Given the funding ratio, the indexation of the accrued benefits will be adjusted according to the pension contract and the price levels generated from the scenario set. The accrued benefit matrix will be adjusted accordingly.

To value the sponsor guarantee and the PPF guarantee options, we also need to consider the evolution of a sponsor's assets and debts, and simulate the insolvency event. In the model, we assume that the sponsor has an asset portfolio that consists of a different asset mix from the pension scheme's asset portfolio. Sponsor's assets evolve in a similar way as the pension scheme's assets: the assets at the end of each year is the sum of the assets at the beginning of the year and the investment returns. The initial sponsor's assets before the model starts running is predetermined. The size of the initial assets determines a sponsor's ability to pay contributions to the pension scheme when there is a pension funding shortfall. It also influences the insolvent probability as we define the insolvency is triggered when the level of the sponsor's assets hits the level of its debts. To strike a balance, we choose the level of the sponsor's assets to be 1.5 times of the level of the pension scheme's assets.

At the end of the year, the model examines whether the sponsor is still solvent. If the sponsor is still solvent, recovery contributions may be paid by the sponsor to the pension scheme according to the funding ratios and the pension contract. If the sponsor is insolvent, the pension scheme will be liquidated. The pension scheme can buy insurance contracts for its participants or the PPF may take over of both the pension assets and liabilities. How the pension scheme is liquidated depends on the funding position of the scheme and if there is the PPF protection in the pension policy. The details are explained when we introduce the pension policies and demonstrate the results. The model uses indicator matrices to record the statuses of the sponsor and the pension scheme, and adjusts the indexation rules, accrued benefits accordingly.

The above process is repeated for 15 years. In each time loop, the cash flows, the assets and liability levels, and the indexations are recorded so that we can value the embedded options in the pension policies.

A.2. Valuation

The pension policies can be viewed as the financial contracts between the stakeholders of the pension scheme. Participants in a conditional indexation contract receive less than full indexation when the funding ratio is low. The sponsor needs to contribute to the recovery of the pension scheme when the financial market performs badly and there is a pension funding shortfall. The PPF has to step in to guarantee part of the pension deficit when the sponsor defaults. The payoff of the pension contracts depends on the market contingency. Therefore, we can view these contracts as a combination of contingent claims and value the contracts using the fundamental theory of asset pricing (FTAP) Harrison and Pliska (1981); Delbaen and Schachermayer (1994).

The price of a financial asset has many possible outcomes in the future under the real probability measure $\mathbb{P}$. We define the asset whose price process is always positive definitive as the *numéraire*. Assuming the asset portfolio is self-financing, i.e. returns are reinvested and no inflow of money from external source, the FTAP states that if there is no arbitrage in the market and there exists a *numéraire*, the process of the relative price (relative to the *numéraire*) of a financial asset is a martingale process under an equivalent risk-neutral measure $\mathbb{Q}$. Furthermore, if the market is complete, meaning that any contingent payoff can be replicated by a combination of financial assets, the measure $\mathbb{Q}$ is unique.

For example, we choose a risk-free bond with continuous interest rate r as the *numéraire*. If the bond has a price of 1 at time 0, the bond price at time t will be e^{rt}. According to the FTAP, the relative price process of an asset X_t has the relation

$$\frac{X_t}{e^{rt}} = E^{\mathbb{Q}}\left[\frac{X_T}{e^{rT}}\right]. \tag{18}$$

Therefore, the present value X_0 is $E^{\mathbb{Q}}[\frac{X_T}{e^{rT}}]$. Note one can select any assets with a positive definitive price process as the *numéraire* and the growth rate of the asset is not necessarily constant.

To value the embedded option within the pension policies, the value-based ALM model generates scenarios under the risk-neutral measure $\mathbb{Q}$. The contingent payoffs of the contracts are recorded and discounted with the appropriate risk-free rates. Taking the average of the discounted payoffs will give the value of the particular embedded option.

A.3. Scenario set

A risk model is used to generate economic scenarios. The risk factors, such as stock returns and bond returns, term structure of interest rates, price levels from the generated scenario set are used as the input variables in the value-based ALM model, so that the outcomes of the pension scheme's assets and liabilities can be simulated. The risk model deserves a paper on its own and here we only introduce some basic information.

The ALM model is based on Monte Carlo simulation of 5000 possible future economic development (Van den Goorbergh et al., 2011). The state variables are modelled with a vector autoregressive model with jumps and time-varying volatilities:

$$\mathbf{x}_{t+1} = \begin{bmatrix} \pi_{t+1} \\ y_{t+1} \\ xs_{t+1} \\ dy_{t+1} \\ cs_{t+1} \\ mp_{t+1} \end{bmatrix} = \mathbf{c}_t + \boldsymbol{\Gamma}\boldsymbol{x}_t + J_{t+1} + \boldsymbol{\Sigma}\boldsymbol{S}_t^{1/2}\zeta_{t+1}, \tag{19}$$

$$\mathbf{c}_t = (\mathbf{I}_6 - \boldsymbol{\Gamma})(\mu_0 + \mu_{\bar{\pi}}\bar{\pi}) - \mathbf{p}\nu, \tag{20}$$

$$\zeta_{t+1} \sim \mathbb{N}(\mathbf{0}, \mathbf{I}_6). \tag{21}$$

π_{t+1} is the log of the annual inflation in the Euro zone, y_{t+1} the Euribor three month rate, xs_{t+1} the excess return on stocks, dy_{t+1} the dividend yield, cs_{t+1} the credit spread and mp_{t+1} the maturity preference. $\bar{\pi}_t$ stands for deterministic inflation target. Jumps are

modelled by the jump indicator J_{t+1} with probability $\mathbf{p}$ and size ν, and the time varying volatility is obtained by diagonal matrix $\mathbf{S}_t$.

Before the recent financial crisis, most models regard the 2008 event as highly unlikely. The scenario generator we use improve on this by introducing the jumps into the model. The model assumes a constant probability of a jump that stands for a sudden drop in the confidence in the market, accompanied by the plunge in stock market, lowering interest rate and high credit spreads.

The term structure is obtained from an affine term structure model. The parameters are calibrated to the historical data. The derived rates are used to value the liabilities and cash flows in the scenario set so that everything is valued in a market-consistent manner. For more explanation of the model, one can refer to Van den Goorbergh et al. (2011).

The value-based ALM model aims to value embedded options using risk-neutral asset pricing technique. For this purpose, the real world scenarios are transformed to the risk neutral measure (Lin and Vlaar, 2011). The ALM model for the pension fund also contains an additional variable, the average wage growth. Since wage growth is not traded in the market, a regression model for the wage growth w_{t+1} with lagged wage growth w_t, inflation π_{t+1} and lagged short term interest rate y_t is estimated under $\mathbb{P}$ measure to generate scenarios:

$$w_{t+1} = \alpha + \beta_w w_t + \beta_\pi \pi_{t+1} + \beta_y y_{t+1} + \epsilon_{t+1}. \tag{22}$$

The parameters from (22), together with the dynamics of π and y under $\mathbb{Q}$ measure, are used to generate the dynamics of wage growth under $\mathbb{Q}$ measure:

$$w^{\mathbb{Q}}_{t+1} = \alpha + \beta_w w^{\mathbb{Q}}_t + \beta_\pi \pi^{\mathbb{Q}}_{t+1} + \beta_y y^{\mathbb{Q}}_{t+1} + \epsilon_{t+1}. \tag{23}$$

Appendix B. Calculation of the PPF levies

B.1. The PPF levy formula

The PPF publishes how the levy charges are calculated in its annual publications[5] (PPF, 2012c). The calculations are based on both the funding position of a pension scheme and the insolvency risk of its sponsor or sponsors. The PPF sets up a target of the total levies it collect during the years for three years and determine the parameters used in the levy formula accordingly. This means that the parameters vary from year to year. Therefore, it is difficult to estimate the parameters beyond three years. To avoid the difficulties of the calculation, we assume that the parameters remain unchanged after three years.

The levy is the sum of two parts: the scheme-based pension protection levy (SBL) and the risk-based pension protection levy (RBL). The formula to calculate the SBL is:

$$UL \times SLM, \tag{24}$$

where *UL* is unstressed liabilities and *SLM* denotes 'scheme-based levy multiplier' that equals 0.000056 for 2013/14. Since we do not distinguish stressed and unstressed liabilities in our model, we use the present value of the pension liabilities as *UL*.

RBL is calculated as

$$U \times IR \times LSF \tag{25}$$

where *U* is the pension underfunding, *IR* is the measure of the insolvency risk, and *LSF* is the 'risk-based levy scaling factor' that equals 0.73 for 2013/14.

[5] The PPF levy is calculated based on the information provided by the PPF. But the levy we calculated may not be the actual amount that the PPF will charge a pension fund. Since the stochastic model used by the PPF is not in public, the best we can do is to set the levy to our best estimation of the value that the PPF will set the levy at. In addition, the actual levy will be higher than our calculated value if the stressed assets are used in the levy formula.

The PPF employs Dun & Bradstreet to provide monthly failure score of the sponsors of the pension schemes. According to the failure score each sponsor is categorised to one of ten risk bands. There is a *IR* value assigned to each of the risk bands. The *IR* ranges from 0.0018 for the least risky band to 0.04 for the band with highest risk. The failure score of a sponsor depends on its location, industry and other factors. The *IR* for each risk band is in Table 9.

In our model, we only assume the assets and debts of the sponsor. Therefore, we cannot assign the sponsor in our model to a specific risk band. To be prudent, we choose the *IR* for the highest risky band for our calculation of *RBL*, which is 0.04.

In addition, to avoid the levy charges imposing too much stress on the pension scheme's funding position, the PPF sets up a cap for the *RBL*. The cap is

$$UL \times K, \tag{26}$$

where *UL* is the unstressed liabilities of the scheme, and *K* is the 'RBL cap' set by the PPF, which equals 0.0075 for 2013/14.

In summary, we calculate the annual PPF levy in our model as

$$\begin{aligned} Levy &= SBL + RBL \\ &= UL \times SLM + min\{U \times IR \times LSF, UL \times K\}. \end{aligned} \tag{27}$$

B.2. Adjustment of the assumptions in the PPF levy formula

From Eq. (27), we can see that different assumptions of the pension scheme financial positions and its sponsor's insolvent probability will affect the value of the PPF levy charge. This section provides several variants of the PPF levy calculation, so that one can see the effect of a changing assumption on the value of the PPF levy option on the HBS.

The PPF sets a cap when calculating the *RBL* (*K* in Eq. (26)). We observe from our simulation results that the cap plays an important part in the *RBL* calculation. A pension scheme with a highly risky profile (large underfunding or highly risky sponsor, or both) might have a high *IR* value (for example 0.04), whereas the cap can limit the value of *RBL*, thus resulting in a lower PPF levy than without such a cap. We thus remove the cap by setting *K* in Eq. (27) to 1 in our simulation and set up Policy A. The HBS of Policy A is shown in Table 10. Removing the cap increases the value of the levy option by almost 4 folds. Correspondingly, the value of the PPF guarantee option increases, reflecting the fact that higher levy charges deplete more assets of the pension scheme.

In our calculation of the PPF levy (Eq. (27)), we assume a fixed value of *IR* (0.04 in Policy 5). The PPF defines *IR* to be the one-year insolvent probability of the sponsor of the pension scheme. Therefore, ideally, the value of *IR* in a Monte Carlo simulation is path-dependent and reflects the one-year insolvency probability of the sponsor. For this reason, Policy B is set up so that the levy charges in the simulation are path-dependent. We assign the sponsor to a risk band based on its debt-to-asset ratio. A sponsor with the debt-to-asset ratio of (0, 0.1] is assigned to risk band 1 (Table 9), and a sponsor with the debt-to-asset ratio of (0.1,0.2] is assigned to risk band 2, and so on. This way of segregation does not reflect the true one-year insolvent probability of a sponsor, but it does provide a path-dependent calculation of the PPF levy charges. For example, a sponsor with the debt-to-asset ratio of 0.65 will have a higher *IR* value, thus higher levy charge, than a sponsor with the debt-to-asset ratio of 0.35. In addition, Policy B does not have a cap on the *RBL* ($K = 1$ in Eq. (27)). The HBS of Policy B is presented in Table 10. The value of the PPF levy option in Policy B is reduced by around 50%, compared to that in Policy A. This is because we assume the highest possible value of *IR* (0.04) for all scenarios in Policy A, whereas the value of *IR* in Policy B becomes path-dependent and is less than 0.04 in most scenarios.

Table 9
Table of *IR* corresponding to the risk band. Note this is set for the year 2013/14. Future values probably will change.

Risk band	1	2	3	4	5	6	7	8	9	10
IR	0.0018	0.0028	0.0044	0.0069	0.011	0.016	0.0201	0.026	0.0306	0.04
Score[a]	100–99	98–96	95–92	91–87	86–73	72–66	65–46	45–38	37–30	29–1

[a] Score is the Employer Failure Score the PPF uses to assign the pension scheme to a certain risk band.

Table 10
Re-calculations of PPF levy by changing the assumptions of the parameters in the PPF levy formula. Policy 5 is described in Section 3. Policy A removes the cap for the *RBL* by setting K in Eq. (26) to 1. Policy B is based on Policy A and allows *IR* from Eq. (25) to be path-dependent in the simulation. The *IR* in Policy C, D and E are also path-dependent, and are multiplied by an adjusting factor of 2, 0.5 and 4, respectively.

	Policy 5	Policy A	Policy B	Policy C	Policy D	Policy E
Pension assets	117.50	117.50	117.50	117.50	117.50	117.50
Sponsor guarantee	14.49	14.76	14.52	14.66	14.46	14.93
PPF guarantee	7.90	8.39	8.09	8.48	7.92	9.41
PPF levy	−0.52	−1.96	−0.94	−1.93	−0.49	−4.29
Total	139.36	138.68	139.17	138.71	139.38	137.55
Pension Liabilities	100.00	100.00	100.00	100.00	100.00	100.00
UK indexation	21.54	21.53	21.53	21.53	21.54	21.53
PPF cut	−1.13	−1.13	−1.13	−1.13	−1.13	−1.14
Residue	19.00	18.28	18.77	18.31	18.97	17.16
Surplus option	22.80	22.57	22.72	22.67	22.75	22.63
Deficit option	−3.80	−4.29	−3.95	−4.36	−3.78	−5.47
Total	139.36	138.68	139.17	138.71	139.38	137.55

As we can see from the above exercise, in Policy B, a highly leveraged sponsor with the debt-to-asset ratio of 0.9 will have a *IR* value of 0.04 in the calculation of the PPF levy charge. One would argue that a sponsor with such a high leverage will have a much higher insolvent probability than 0.04. In addition, sponsors with the same leverage ratio from different industries may differ in likelihood to become insolvent in one year (e.g. compare a bank and a chemical plant). To give our model more flexibility, we multiply the *IR* values of each risk band by an adjusting factor to reflect the difference of various sponsors from different industries. If a company in an industry that has a factor of 2, for example, the sponsor in the risk band 6 will have an *IR* value of 0.032, twice of that from a sponsor in Policy B (0.016). We set up Policy C, D and E with the multiplying factor of 2, 0.5 and 4, respectively, and their HBS are shown in Table 10. One can see that the value of the PPF levy option changes roughly in proportion to the multiplying factor. It is also interesting to notice that Policy E with a multiplying factor of 4 has the PPF levy option with a value of 4.29, much closer to the value of PPF guarantee option (9.41). All these suggest that the one-year insolvent probability is an important factor in determining the value of the PPF levy option.

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