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Investment risk-taking and benefit adequacy under automatic balancing mechanism in the Japanese public pension system

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The automatic balancing mechanism introduced in 2004 aims to re-establish the financial equilibrium of the Japanese public pension systems. The non-linear functions for benefits embedded in the automatic balancing mechanism make it challenging to analyse the impact of market fluctuations on the adequacy of benefits and the sustainability of the pension system. Using a stochastic simulation model applied to the government's public pension verification programmes, the risk of benefit levels and financial stability according to risk-taking in pension reserve funds for the Japanese public pension system is investigated. The Japanese public pension system is characterised by a pay-as-you-go system with substantial reserve funds. Benefit adequacy is measured by the replacement rate and financial sustainability by the reserve-to-expenditure ratio. The results show that for a high level of risk-taking in the reserve fund, the risk of benefits increases because the automatic balancing mechanism reduces benefits until the pension system recovers solvency. In addition, the risk of reserve funds increases because of the possibility of sizeable negative investment returns. In contrast, when risk-taking is low, the benefit level is locked in at a low level because investment returns are insufficient. Therefore, moderate risk-taking of reserve funds should be adequate.

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Introduction

For countries and regions where the birth rate is declining rapidly and population ageing is accelerating, it is necessary to continuously verify the financial situation of the public pension system to maintain long-term sustainability. Since the public pension system plays an essential role in supporting a large part of household expenditures, the adequacy of its benefits must also be examined.[1] The Organization for Economic Co-operation and Development (OECD, 2021a) has discussed the challenges common to pension systems in developed countries: The sustainability of these systems must be maintained while ensuring sufficient benefits. However, it is challenging to implement policies that fulfil both simultaneously because providing adequate benefits is a factor that worsens the health of the system. Therefore, we conduct a novel stochastic simulation study using the Japanese government's official pension verification programmes. We contribute to the policy debate on the risk of benefit levels and the long-term financial sustainability of the Japanese public pension system by focusing on the investment risk-taking of the reserve fund, which affects the benefit level and sustainability.

The problems of the public pension system are generally caused by the trends of the birth rate, the ageing of the population, increasing longevity, declining productivity growth, and these fluctuations. However, social security systems, including public pensions, have been established and reformed through political processes. Cremer and Pestieau (2000) argued that economic and demographic factors play a relatively minor role in the pay-as-you-go pension system's problems, but political factors are far more critical. For example, politicians may offer higher pension payments as subsidies for winning elections without sufficient contributions to cover them. Another problem for public pension systems is their inability to develop a credible institutional framework for contributors and pensioners in which the promise of payments is reasonably respected (Besley and Prat, 2005).[2]

An automatic balancing mechanism (ABM) for a public pension scheme is a set of legally defined measures that are automatically applied depending on the solvency or sustainability indicator. It aims to restore the financial equilibrium of pay-as-you-go pension schemes through successive applications to make them viable without repeated intervention by the legislator (Vidal-Meliá et al., 2009). Recently, many countries have adopted an ABM, including Sweden, Canada, Germany, Finland, and Japan.[3] There are several ways to view this mechanism. ABM features range from simple solvency tests to complex multi-factorial approaches that increase the burden on contributors and beneficiaries to make the system solvent. An example of the former is the Canadian system, where the contribution rate (tax rate) automatically increases under predetermined conditions. The second example is the Swedish ABM, which provides for the automatic adjustment of benefits. The United States (US) social security system includes specific ABM features, such as a cost-of-living adjustment (American Academy of Actuaries, 2011).

Regarding the public pension system in Japan, an ABM was introduced in 2004, accompanied by a fixed (capped) pension premium.[4] The Japanese ABM is classified into a scheme of benefits linked to life expectancy, demographic ratios, and wage growth by the OECD (2021a). Real pension benefits are reduced based on the negative growth rate of insured persons through modified indexation (*macroeconomic slide* in Japanese terms) to re-establish the financial equilibrium. The reserved fund is used to make up for the shortfall in immediate contributions so that the projected reserve-to-expenditure ratio at the end of the verification period (95 years later) is one, meaning that the pension reserve fund equips 1 year of total expenditure. The reserve-to-expenditure ratio (RER) is defined as the reserve fund amount of the previous year over the total pension expenditure, including benefit payments.

Meanwhile, the government has a target replacement rate to measure the adequacy of pension benefits. The replacement rate (RR) is the ratio of pension benefits to the income of insured persons. A representative household is assumed for both benefits and income. The current RR is approximately 60%, and the government's target is at least 50% (Ministry of Health, Labour and Welfare [MHLW], 2020a). Under Japan's ABM, the government and the Government Pension Investment Fund (GPIF) can only control the investment risk-taking of the reserve funds, which could cause significant fluctuations in the RR and RER. In this context, a stochastic simulation study is required to assess the adequacy of the benefits and sustainability of the pension system.

Regarding the financial verification of the public pension system in Japan, the MHLW (2019a) has set up several scenarios for future population and economic conditions and predicted the changes in the value of future pension reserve funds and RR without using a stochastic simulation. For future population, the MHLW (2019a) uses the National Institute of Population and Social Security Research (2017) and assumes three scenarios (medium, high, and low) for total fertility and mortality rates. For economic assumptions, MHLW (2019a) uses Cabinet Office (2019) for two short-term scenarios to 2028 and then considers several long-term economic scenarios, including economic growth and labour force participation assumptions under the government's standard assumptions (Cases 1 to 3), lower assumptions (Cases 4 and 5), and risky situations (Case 6). The values of future pension reserve funds and RR were predicted separately for each scenario. However, even if one of these scenarios occurs as a long-term average, economic conditions and financial markets will fluctuate in the short-term, and the RR and RER will fluctuate accordingly. Furthermore, the risk of the pension system is not straightforward because of the ABM; thus, it cannot be analysed by a simple scenario-based prediction. The characteristics of the pension system are complex and similar to those of derivative products in financial markets. Even if a simple scenario-based prediction can analyse the future on average, the risks of RR and RER can hardly be captured without a stochastic simulation (Kitamura et al., 2006).

Previous studies use stochastic simulation models to estimate probability distributions and confidence intervals as indicators of the future financial status of the pension system.[5] The analysis provides insights that supplement future forecasts in addition to the scenario analysis for the RR and RER (Board of Trustees, Federal Old-Age and Survivors Insurance, and Federal Disability Insurance Trust Funds, 2020; Giang and Pfau, 2008). Moreover, as public pensions are complex systems and there are interactions among variables, it is difficult to analyse their risk using a simple model; their risk should be explicitly analysed with stochastic simulations (Castañeda et al., 2021; Chen and Matkin, 2017; Mielczarek, 2013). It is challenging to interpret the RR and RER in the context of the Japanese ABM with a scenario-based simple analysis; therefore, a probabilistic simulation model is required (Kitamura et al., 2006; Nakashima and Kitamura, 2021; Usuki et al., 2003). In particular, the risk-taking of reserve funds is a crucial factor for the future financial condition of public pensions in Japan (Kitamura et al., 2006; MHLW, 2020b) and the only decision parameter that the government can control.

Moreover, previous studies examine the effectiveness of ABMs for benefit adequacy and financial sustainability of the public pension system (Boado-Penas et al., 2020; Devolder et al., 2021; Fujisawa and Li, 2012; Vidal-Meliá et al., 2009). For example, Vidal-Meliá et al. (2009) study the introduction of ABM in the

Spanish public pension system, where the level of insolvency is high, and there is a clear problem of structural actuarial imbalances. They find that ABM and official solvency indicators provide a credible institutional framework that can be used to increase the probability of pension payment promises and minimise the use of the pension system as an electoral tool. Furthermore, Boado-Penas et al. (2020) assess the adequacy and sustainability of a pay-as-you-go pension system using an ABM. Countries such as Australia, Canada, Norway, Sweden, Latvia, Poland, and Japan have public pension systems with pay-as-you-go elements and investment funds. They consider different risk-taking strategies for the investment fund of the pension system. Using the non-linear optimisation proposed by Godínez-Olivares et al. (2016), they find trade-offs between financial sustainability and adequacy of the system. For example, a higher allocation to equity increases the probability of a higher RR. Fujisawa and Li (2012) examine the effect of an ABM on pension benefits in Japan. They use a stochastic simulation model in which mortality and fertility rates change stochastically, calculate the present value of the difference between the real benefits with and without an ABM, and estimate the average deficit and its value at risk (VaR).

Using a stochastic simulation model that applies the government's public pension verification programmes used in MHLW (2019a), we examine the adequacy and sustainability of the Japanese public pension system as a function of the risk-taking of pension reserve funds. Adequacy and sustainability are measured by the RR and RER, and risk-taking is measured by the stock weight (SW), the percentage of investments in stocks (including domestic and foreign stocks) in total reserve funds. We consider investments in traditional asset classes: domestic stocks, domestic bonds, foreign stocks, and foreign bonds. We use only the medium variant of population projections to focus on economic fluctuations. Our assumptions for the stochastic simulation are based on two government economic cases: Case 3 (the third-highest growth scenario: standard scenario) and Case 5 (the second-lowest growth scenario: pessimistic scenario) in the MHLW (2019b), hereafter referred to as economic assumptions 3 and 5, respectively.[6] Primarily, we focus on economic assumption 5 because we analyse the downside risk of RR and RER.

We contribute to the literature by examining the future joint distributions of RR and RER under ABM in different stock risk-taking settings. The RR and RER are essential parameters for measuring the adequacy and sustainability of the public pension system. In particular, we simultaneously assess the downside risk of these measures, although the literature examines them separately. We demonstrate that both the RR and the RER have significant downside risks despite the existence of the ABM; the RR can be less than half, and the RER can be exhausted (RER < 0) with a certain probability. In addition, we apply dynamic investment strategies under the ABM, where the SW is changed according to the RER level. The dynamic investment strategies we consider are portfolio insurance and contrarian strategies. We then study the impact of these strategies on the downside risks of RR and RER. These studies have not yet been addressed in the literature.

Boado-Penas et al. (2020) consider different equity risk-taking patterns in an ABM framework. Although their outcomes are similar to our study, including a version of RER and RR, their decision variables are the contribution rate, pension age, and pension indexation rate. Unlike them, our decision variable is equity risk-taking, the only decision variable the government has under ABM; the contribution rate, pension age, and pension indexation rate are predetermined. As for studies in Japan, Fujisawa and Li (2012) investigate the financial sustainability of the Japanese public pension system under ABM using a stochastic simulation model. However, their model treats mortality and fertility rates as stochastic: they do not consider the stochastic change in economic variables such as inflation and wage growth rates. Using a stochastic simulation method applied to the government verification programme in 2014, Hizu (2020) examines the RER in Japanese public pensions. However, the author does not consider the risk-taking of the reserve fund and RR, which is the main theme of this study. Nakashima and Kitamura (2021) study the RR of basic pension and employees' pension insurance using a simple original stochastic simulation model. Their main objective is to examine the effectiveness of pension revision plans, and they do not consider the RER and risk-taking of pension reserve funds.

We find that the pension reserve fund should take an adequate risk when investing in stocks. For high-risk investments such as SW = 100%, there are many cases where the ABM does not stop during our simulation periods. The RR and RER continue to decline in these cases. For low-risk investments, such as SW = 0% (domestic bonds only), the investment returns are insufficient, and the RR declines almost certainly to two-thirds or less of the current RR. By contrast, middle-range investment risk-taking (between 25% and 75%) is better. Second, our results show that the pension reserve fund could be exhausted for a certain probability. We estimate the government's obligation to compensate for the shortage of reserve funds and find that the government has a risk of a considerable burden in some cases. Third, we consider dynamic investment strategies and find that portfolio insurance can limit the downside risks of RR and RER, while a contrarian strategy increases the median value of RR and RER. Finally, the government may temporarily increase its liabilities, the negative RER, to finance the payment of benefits as the ABM further reduces its benefits and eventually restores solvency.

An international reader may benefit from this study as follows: Japan has the oldest population and a large public pension system, and this public pension system has a large reserve fund and invests in stocks. Therefore, it is valuable for researchers and policymakers to study how the ABM works in such an established pension system depending on the different risk-taking in stocks. The discussion on the adequacy and sustainability of the public pension system with reserve funds is helpful for countries with an ABM and those considering its introduction in the future.

The remainder of this paper is organised as follows. Section "Simulation method and assumption" explains the simulation method, and section "Results" presents the results. Finally, section "Conclusions" concludes the paper.

Simulation method and assumption

Simulation procedure. The MHLW (Ministry of Health, Labour and Welfare) discloses the calculation programme used to verify the actuarial valuations every 5 years (MHLW, 2019b). Actuarial valuations include predictions of the long-term status of financial conditions, such as the projection of future premium revenue and benefit expenditure over an approximately 100-year period. These require assumptions about future demographic, social, and economic conditions. Multiple sets of assumptions covering a range of possible scenarios were used. Figure 1 illustrates the actuarial verification process implemented using MHLW's computer programme written in FORTRAN and C++.[7] The initial assumptions are mainly the current number of insured persons, the population projection, and the projected labour force participation rate. Then, the number of insured persons in the future is projected. Second, the number of future pensioners is projected based on the current number of pensioners, pension plan participation rates, and pension rules, such as pension age and benefit payments. Third, as explained below, pension benefits and premium revenue are projected using the wage growth rate, inflation

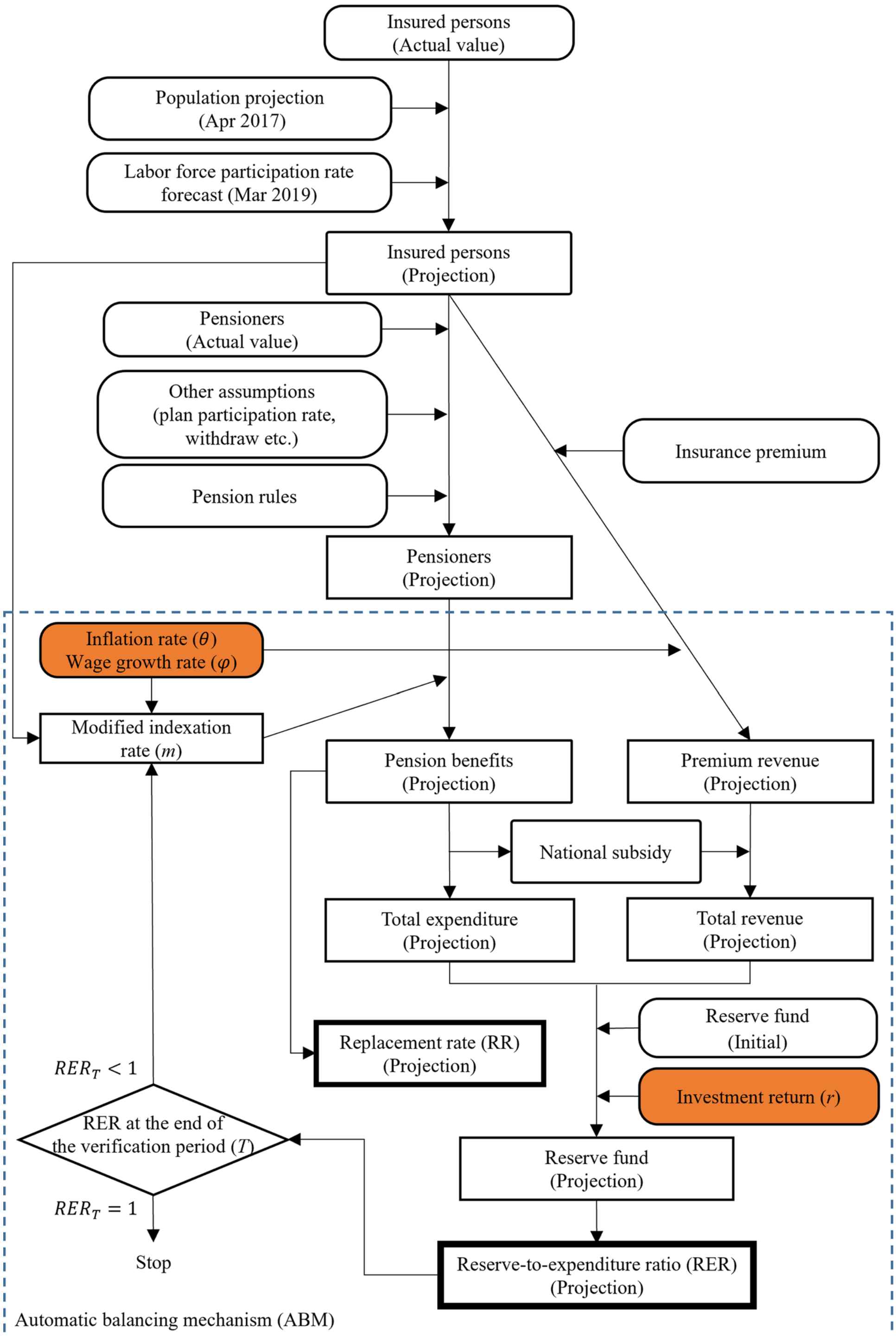


Fig. 1 Actuarial verification model. The actuarial verification process implemented using MHLW's computer programme. Our stochastic variables are the inflation rate, wage growth rate, and investment return.

rate, and modified indexation rate. Fourth, total expenditure including pension benefits and total revenue are projected considering the national subsidy. Fifth, the value of the pension reserve fund is projected using investment returns. The investment returns differ according to the SWs in this study. This study considers five SWs: SW = 0%, 25%, 50%, 75%, and 100%. Finally, the RR and RER, the main measures in this study defined below, are projected. We repeatedly run this set of programmes by stochastically changing the inflation rate, wage growth rate, and investment returns. The start year of the simulation is 2019, and the end year is 2115. We conducted a Monte Carlo simulation with 9000 replications for each SW and economic assumption (explained below) using a large-scale computer at one of the authors' institutions.

Modified indexation rate, replacement rate (RR), and reserve-to-expenditure ratio (RER). According to the ABM, the pension benefits for pensioners in the basic pension (BP: the first tier) and employees' pension insurance (EPI: the second tier) and the notional accrual wage amounts for employees' pension insurance are adjusted annually by the modified indexation rate (m):

$$m_{h,t} \equiv Min\left[f\left(\theta_t, \varphi_t\right), Max\left\{f\left(\theta_t, \varphi_t\right) + Min\left(\delta_t - \gamma, 0\right), 0\right\}\right] \cdot I_{\{t \le t_h^*\}} + f\left(\theta_t, \varphi_t\right) \cdot I_{\{t > t_h^*\}},$$
$$t_h^* = inf_{2010 \le t \le T}\{t | RER_{h,T} = 1\} \tag{1}$$

where h represents the public pension system, $h \in \{BP, EPI\}$; θ and φ are the inflation and wage growth rates, respectively; the function f differs depending on the insured persons and pensioners: $f(\theta, \varphi) \equiv \varphi$ for insured persons and $f(\theta, \varphi) \equiv \min(\theta, \varphi)$ for pensioners; δ represents the annual growth rate of the total number of insured persons, which is usually negative; and γ is constant and set to 0.003. The notional accrual wage amounts are used to calculate the pension benefits at the pension-claiming age. The modified indexation rate is applied to the basic pension and employees' pension insurance separately until the year ($t \le t_h^*$) when the predicted RER for the corresponding pension system becomes one at the end of the verification period ($RER_{h,T} = 1$), or equivalently, the pension system re-establishes financial equilibrium. In our simulation, θ and φ are the stochastic variables. The pension benefits fluctuate based on these variables. Furthermore, the investment returns for reserve funds are stochastic. As the RER depends on θ, φ, and investment returns, the year the ABM ends (t_h^*) fluctuates according to these variables. Therefore, the RR and RER fluctuate through the change in t_h^* in addition to changes in θ, φ, and investment returns. After the application of modified indexation ends ($t > t_h^*$), the indexation rate is $f(\theta, \varphi)$.

The notional accrual wage amounts (N) and full basic pension benefits (FB) for each individual (i) are adjusted by the modified indexation rate (m):

$$N_{t,i} = N_{t-1,i}\left(1 + m_{EPI,t}\right) + W_{t,i},$$
$$FB_{t,i} = FB_{t-1,i}\left(1 + m_{BP,t}\right),$$

where W is the standardised wage income for each individual. The pension benefits (B) at the year pension claimed (pc) are:

$$B_{EPI,pc,i} = \pi_{pc,i} \cdot N_{pc-1,i},$$
$$B_{BP,pc,i} = \gamma_{pc,i} \cdot FB_{pc-1,i},$$

where π is the multiplier for determining the employees' pension benefit, and γ is the proportion of insured months to 480 months (for full pension) in the basic pension. The pension benefits (B) for each pension system (h) after the claiming age are:

$$B_{h,t,i} = B_{h,t-1,i}\left(1 + m_{h,t}\right).$$

Our outcomes (RR and RER) are:

$$RR_t \equiv \frac{\sum_{h \in \{BP,EPI\}} Representative\_standard\_benefits_{h,t-1}\left(1 + m_{h,t}\right)}{Representative\_standard\_wage_{t-1}\left(1 + \varphi_t\right)}, \tag{2}$$

$$RER_t \equiv \frac{\sum_{h \in \{BP,EPI\}} Reserve\_fund_{h,t-1}}{\sum_{h \in \{BP,EPI\}} Total\_expenditure_{h,t}}. \tag{3}$$

where $Representative\_standard\_benefits_{h,0}$ is a function of pension benefits of each pension system at the start of the simulation, and $Representative\_standard\_wage_0$ is a function of notional accrual wage amounts at the start of the simulation; those are pension benefits and wage income of a representative household defined in MHLW (2019b, p. 14). $Total\_expenditure_{h,t}$ is the expenditure of each public pension system that depends on total pension benefits ($B_{h,t} \equiv \sum_i B_{h,t,i}$ and other expenditures. These expenditures depend on the modified indexation rate (m). The reserve fund of each pension system is

$$Reserve\_fund_{h,t} = Total\_revenue_{h,t} - Total\_expenditure_{h,t} + Reserve\_fund_{h,t-1}\left(1 + r_t\right), \tag{4}$$

where $Total\_revenue$ is the income of each pension system including premiums and r_t is the investment returns.

Japanese public pension system and investments of the reserve fund. The starting year of our simulation is 2019. For actual public pensions in Japan, the total revenue in 2019 was JPY 52.9 trillion, the total expenditure was JPY 53.3 trillion, and the size of the reserve fund was JPY 190.5 trillion (MHLW, 2019c). The RR was 61.7% (MHLW, 2019b), and the RER was 3.76 in 2019 (MHLW, 2019c). The ABM started in 2015 and, therefore, applied in 2019. In our simulation, the initial value of RR is 61.7%, and the RER is 4.0 (MHLW, 2019b). The RER differs slightly from the above value as the size of a reserve fund sometimes varies depending on coverage, measure, and purpose, such as the difference between market value and book value.

According to the GPIF (2020a, 2020b), it reconstructs its strategic asset allocation (or policy asset mix) of asset classes with allowances from the strategic allocation almost every 5 years, together with the timing of the actuarial valuation of public pensions. A strategic allocation is a long-term target asset allocation for each asset class. The current strategic allocation was determined in 2020. The GPIF uses four traditional asset classes: domestic stocks, domestic bonds, foreign stocks, and foreign bonds. The GPIF sets benchmark indices for each asset class to manage risk or measure investment performance. The benchmarks for domestic stocks, domestic bonds, foreign stocks, and foreign bonds are Tokyo Stock Exchange Price Index (TOPIX) including dividends, Nomura Bond Price Index (Nomura–BPI) excluding asset-backed securities, MSCI All Country World Index (ACWI) excluding Japan including dividends (JPY base), and FTSE World Government Bond Index (WGBI) excluding Japan and China without currency hedge (JPY base), respectively. Approximately 86–94% (62–79%) of stock (bond) investments have been passively managed with their respective benchmarks over the past 5 years, while the remainder has been actively managed (GPIF, 2022). After constructing the strategic allocation, the GPIF monitors and rebalances its portfolio periodically: If the portfolio deviates from the strategic allocation beyond the allowance, the portfolio is rebalanced to the strategic allocation. The strategic allocation is determined considering the actuarial valuation and the economic and capital market environment. The GPIF may change its strategic asset allocation significantly for some periods (e.g., change in 2014: increase in stock allocation from 24% to 50%), while it may remain at small changes for other periods (e.g., change in 2020: stock allocation remains at 50%, domestic bond allocation decreases by 10%, while foreign bond allocation increases by 10%). Regarding alternative assets (e.g., infrastructure, private equity, and real estate), the GPIF has invested in these assets since 2014, and its current balance is approximately JPY 2.1 trillion (GPIF, 2022). It classifies them into traditional asset classes according to their risk and return characteristics, with the restriction that the maximum allocation to them is 5% of total assets.

In our main simulation, we use a constant mix strategy. Once the SW is determined at the beginning of a simulation, it is maintained throughout the simulation. In other words, the SW is rebalanced each year to the predetermined SW. The GPIF also

Table 1 Simulation assumption.

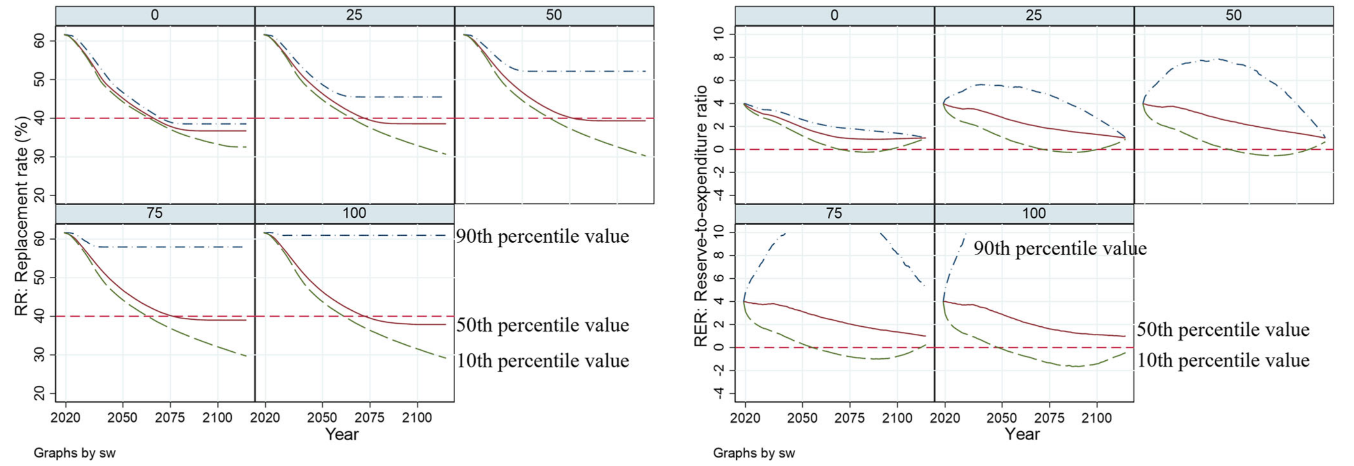
Stock weight (SW)			Inflation	Wage growth rate	Investment return
0%	Mean	Economic assumption 3	1.20%	2.30%	0.70%
		Economic assumption 5	0.80%	1.60%	0.49%
	Standard deviation		0.91%	1.62%	2.56%
	Correlation	Inflation	1.0000	0.5494	0.2590
		Wage growth rate	0.5494	1.0000	0.0420
		Investment return	0.2590	0.0420	1.0000
25%	Mean	Economic assumption 3	1.20%	2.30%	2.84%
		Economic assumption 5	0.80%	1.60%	1.99%
	Standard deviation		0.91%	1.62%	8.38%
	Correlation	Inflation	1.0000	0.5494	−0.0721
		Wage growth rate	0.5494	1.0000	0.0752
		Investment return	−0.0721	0.0752	1.0000
50%	Mean	Economic assumption 3	1.20%	2.30%	4.03%
		Economic assumption 5	0.80%	1.60%	2.82%
	Standard deviation		0.91%	1.62%	12.32%
	Correlation	Inflation	1.0000	0.5494	−0.0753
		Wage growth rate	0.5494	1.0000	0.1027
		Investment return	−0.0753	0.1027	1.0000
75%	Mean	Economic assumption 3	1.20%	2.30%	5.21%
		Economic assumption 5	0.80%	1.60%	3.65%
	Standard deviation		0.91%	1.62%	16.92%
	Correlation	Inflation	1.0000	0.5494	−0.0740
		Wage growth rate	0.5494	1.0000	0.1124
		Investment return	−0.0740	0.1124	1.0000
100%	Mean	Economic assumption 3	1.20%	2.30%	6.40%
		Economic assumption 5	0.80%	1.60%	4.48%
	Standard deviation		0.91%	1.62%	21.75%
	Correlation	Inflation	1.0000	0.5494	−0.0724
		Wage growth rate	0.5494	1.0000	0.1167
		Investment return	−0.0724	0.1167	1.0000

uses this approach to examine the risk and return characteristics of the reserve fund when the GPIF constructs its strategic asset allocation. The asset allocation for SW = 50% in our simulation corresponds to the GPIF's current strategic asset allocation. Other asset allocations could be potential candidates for the GPIF's future strategic asset allocation.

Simulation assumption. Table 1 shows the assumptions used in our simulations. We assume that the inflation rate, wage growth rate, and investment returns follow a normal distribution. As for the parameter settings depending on the economic assumption, the mean values of these variables differ, while we use the same standard deviation and correlations for all economic assumptions. We assume that no significant structural change occurs in the distributions, except for the mean, across the economic assumptions. We also assume that reserve funds invest only in four traditional asset classes: domestic stocks, domestic bonds, foreign stocks, and foreign bonds. Although the OECD (2021b) reports that many private and public pension funds invest in alternative assets, including private equity, venture capital, real estate, and infrastructure, we do not explicitly consider these assets because GPIF's strategic asset allocation only considers the four traditional assets. The OECD (2021b) shows that public pension funds with large assets under management, such as the Social Security Trust Fund in the US, the GPIF in Japan, and the Government Pension Fund—Global in Norway, invest mainly in traditional assets. Investments in alternative assets are limited, partly due to the liquidity problem. The supply of these alternative assets may not be sufficient for large public pension funds, especially in Japan. The mean and standard deviation of each variable and their correlations were taken from the GPIF (2020a). The variables for which no assumptions are made in the GPIF (2020a), such as the correlation between the inflation rate and asset class returns, are estimated using annual data from the last 25 years (1993 to 2017). Table 1 shows the assumptions for our simulations. The mean and standard deviation of the investment returns differ depending on the stock weighting. The correlation between investment returns and inflation and between investment returns and the wage growth rate also differ depending on the SW.

The GPIF's current strategic asset allocation is domestic stocks (25%), domestic bonds (25%), foreign stocks (25%), and foreign bonds (25%). In our simulation, we assume that the domestic and foreign asset classes are equally weighted, as the current strategic allocation weights domestic and foreign asset classes equally. In the case of SW = 25%, domestic and foreign stocks are 12.5% each. Similarly, domestic and foreign bonds are 12.5% each. We run simulations for different domestic and foreign weights to check the robustness of the results in subsection "Robustness checks".

Our economic assumptions are based on the settings of MHLW (2019a, 2019b), which uses Cabinet Office (2019) projections until 2028. Thereafter, the MHLW (2019a, 2019b) estimates economic assumptions using a Cobb–Douglas aggregate production function. The MHLW uses the National Institute of Population and Social Security Research (2017) for the population assumption. Cabinet Office (2019) uses its economic and fiscal model, a kind of IS-LM Phillips Curve style model. Gross domestic product (GDP) growth, inflation, wages, and interest rates are thus determined endogenously. The MHLW uses a Cobb–Douglas aggregate production function for long-term economic assumptions: Real wage growth rates and investment returns. The parameters of the Cobb–Douglas aggregate production function are exogenous in terms of total factor productivity (TFP), capital's share of output, the depreciation rate, and the



(A) Replacement rate (RR) for economic assumption 5 **(B) Reserve-to-expenditure ratio (RER) for economic assumption 5**

Fig. 2 Transition of percentile values of RR and RER for economic assumption 5. A RR for economic assumption 5. **B** RER for economic assumption 5. The lines in the figure represent the transition of the 10th (dashed line), 50th (solid line), and 90th (dash-dot line) percentile values, respectively, in order from the bottom.

ratio of gross fixed capital formation to output. The inflation rates are also given exogenously. In the case of the Cobb–Douglas aggregate production function, depopulation negatively affects the real growth rate and asset returns, as discussed in Arnott and Chaves (2012).

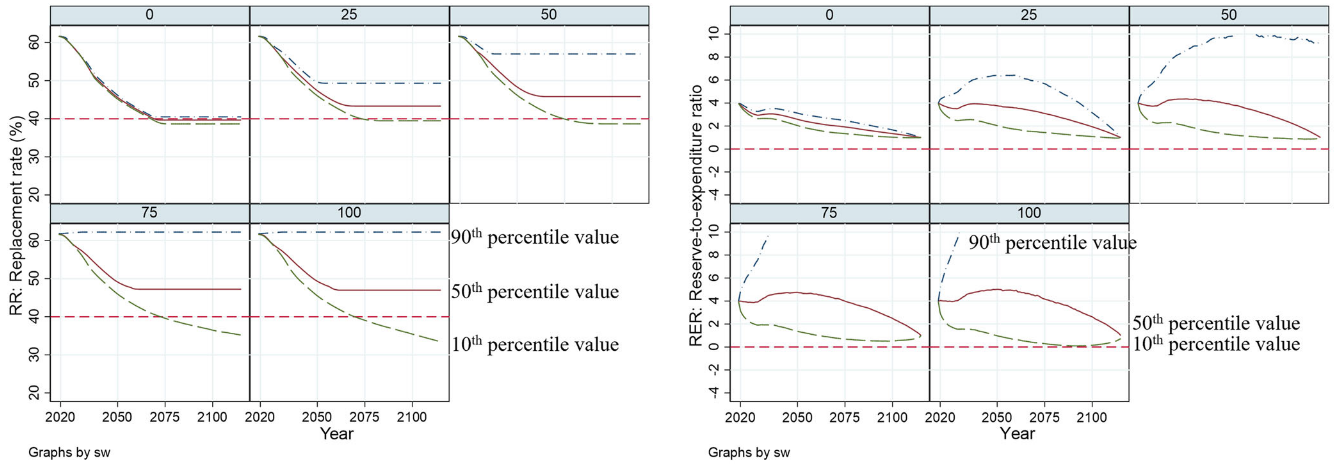
We acknowledge that the default risk on the national debt in Japan is not negligible because it is about twice its GDP and larger than in other countries. In addition, reserve funds considerably invest in Japanese government bonds (JGBs), which indicates that reserve funds face considerable default risk. However, our simulation assumes no default risk for the Japanese government; therefore, the public pension system does not face default risk for the JGBs. The default risks of the Japanese government and the public pension system are beyond the scope of this study and will be investigated in our future research.

In Japan, the ABM aims to control the RER with the RR policy target. The RER and RR transitions are built into the ABM and cannot be intentionally changed once the law is implemented. The only variable that the policy can change is the SW. The policy sets the RER to be one at the end of the verification period. Once this target is set, it is controlled by the ABM. However, as economic conditions fluctuate, the RER may not be 1 in the final verification period. This value may also fall below zero. Unlike the RER, the RR is changed by the ABM, but it is not automatically controlled to achieve a specific policy target (e.g., RR ≥ 50%). RER and RR risks need to be managed because economic conditions fluctuate. Since RER and RR can vary, these risks need to be examined jointly. It is also necessary to discuss both the situation in the last year of the simulation and the levels of these measures before the last year. The ABM unilaterally lowers the RR, and the RER becomes one in the last year of the verification period due to the ABM. However, their development is complicated by the timing of the termination of the ABM. The RER may fall very low in some cases but not in others; it falls and rises or vice versa.

Results

Transitions of marginal distribution for the replacement rate (RR) and reserve-to-expenditure ratio (RER). Figure 2 illustrates the transition of percentile values by year and stock weight (SW) for economic assumption 5 (pessimistic scenario). Panels (A) and (B) illustrate the results for the RR (replacement rate) and the RER (reserve-to-expenditure ratio). The RR represents the public pension benefits for pensioners over the wage income of the insured, simulated by Eq. (2), and the RER represents the reserve fund amount of the previous year over the total pension expenditure, simulated by Eq. (3). Both indicators are measured on a total public pension basis: the sum of the basic pension and employees' pension insurance, given the government's standard family structure assumptions. For each panel, the lower, middle, and upper lines represent the 10th (dashed line), 50th (solid line), and 90th (dash-dot line) percentile values, according to the SW (stock weight): SW = 0% (domestic bonds only), 25%, 50% (GPIF's current strategic asset allocation), 75%, and 100% (stocks only). The RR remains at the same level and graphically horizontal after the ABM stops, indicating that the pension system re-establishes financial equilibrium.

Panel (A) displays the transition of percentile values of the RR with the passage of the simulation year for economic assumption 5, according to the SW. Generally, increasing SW tends to decrease the 10th percentile value and increase the 90th percentile value of the RR; however, the effect of the ABM on the RR differs according to the SW. The 10th percentile values are below 40% in around 2060 and continue to decrease as the SW rises. This decrease is because there are some sample paths in which the ABM for the basic pension does not stop during the simulation period. Thus, the ABM continues to decrease the benefit level.[8] These sample paths consist of nearly 7%, 20%, and 26% of the total sample paths in the cases of SW = 0%, 50%, and 100%, respectively. The 90th percentile values increase with increasing SW. However, the lines for SW = 75% and 100% are similar because there is an upper limit to the increase in the RR. As the modified indexation rate (m) of the RR is defined by Eq. (1), future RR does not exceed the current RR. In Eq. (1), the modified indexation rate (m) is at most wage growth rate (φ) by definition. In Eq. (2), the growth rate of the numerator of RR is at most φ, and that of the denominator is always φ. Therefore, RR can only decrease or maintain the current level (approximately 60%).[9] In addition, there are many sample paths in these SWs where ABM ends earlier and remains at a higher level than government verification. The sample paths where ABM ends before 2030 account for almost 9% and 12% of the total sample paths in the basic pension for SW = 75% and 100%, respectively. They are approximately 27% of the total sample paths in the employees' pension insurance for SW = 75% and 100%. The 50th



(A) Replacement rate (RR) for economic assumption 3 **(B) Reserve-to-expenditure ratio (RER) for economic assumption 3**

Fig. 3 Transition of percentile values of RR and RER for economic assumption 3. A RR for economic assumption 3. RER for economic assumption 3. **B** The lines in the figure represent the transition of the 10th (dashed line), 50th (solid line), and 90th (dash-dot line) percentile values, respectively, in order from the bottom.

percentile values reach about 40% and remain similar for all SW, although the government target is 50%.

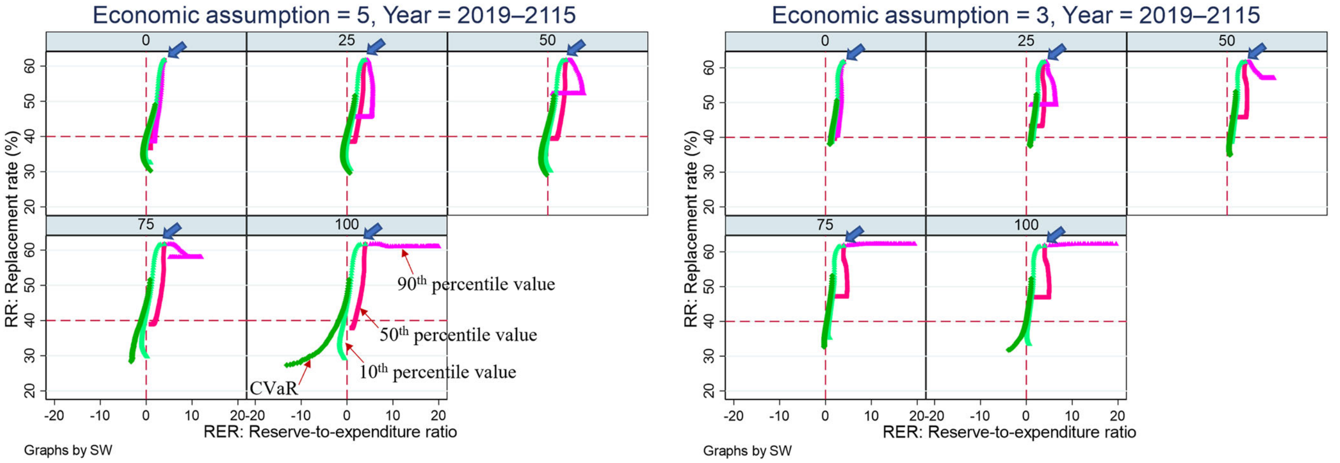
Panel (B) illustrates the change in the distribution of the RER for the total public pension under economic assumption 5 according to the SWs.[10] The RER should be one in the last year of the simulation period, according to the ABM, for both the basic pension and employees' pension insurance.[11] However, the RER can be more than one during the simulation periods for the sample paths if investment returns are high and the ABM ends early. By contrast, it can be less than one if the ABM does not stop even in the last year, which means that the financial condition of the public pension is not recovered, and pension benefits continue to be reduced. The current reserve fund balance for the employees' pension insurance at the end of 2018 is JPY 200.0 trillion, whereas that of the basic pension is JPY 11.5 trillion. Thus, the employees' pension insurance greatly affects the overall funding level. In addition, even if the RER falls below one during the simulation period, it can recover to one towards the end of the simulation period for some sample paths because the ABM further reduces pension benefits. As predicted, the 50th percentile values for any SWs mostly decline and reach one at the end of the simulation period. The 10th percentile values decline during the early simulation periods mainly because of low (negative) investment returns. They can be below zero for all SWs, meaning the pension reserve fund can be depleted during the simulation period. For example, the 10th percentile value for SW = 50% becomes negative in 2065–2106 and reaches approximately −0.5. It then increases in the later simulation periods because of the reduction in benefits by the ABM. However, the 10th percentile values of the RER do not attain one at the end of the simulation period for all SWs, except SW = 0%. Some sample paths exist where the ABM does not stop, even in the last year of the simulation period, and the pension system does not re-establish financial equilibrium. The 90th percentile values rise first during the early simulation periods because of the higher investment returns for SW = 25 or more and then fall because the high benefits are maintained owing to the early stop of the ABM.

Panel (A) in Fig. 3 illustrates the result of the RR under economic assumption 3 (standard scenario): the general tendency of the effects of the SWs is almost similar to that of economic assumption 5, whereas the overall levels of the RR are generally higher because the investment returns are higher than in economic assumption 5. The ABM thus continues for a shorter period than economic assumption 5. The 10th percentile value decreases as SW increases. It bottoms out and remains at the same level for SW = 0%, 25%, and 50% after the ABM ends, restoring financial equilibrium. In contrast, it decreases when SW = 75% or more because there are sample paths where the ABM for the basic pension does not end during the simulation period, and thus the benefit level continues to decrease. The RR has a lower limit in these cases because some components of the modified indexation rate are predetermined in our model and have a lower bound during our simulation periods.[12] These sample paths for the basic pension consist of nearly 10% and 14% of the total sample paths for SW = 75% and 100%, respectively.[13] The 90th percentile values increase with the SW increase, but the lines for SW = 75% and 100% are similar because of the upper limit. There are many sample paths in these SWs where the ABM stops before 2030, approximately 20% and 60% of sample paths for the basic pension and employees' pension insurance, respectively. The 50th percentile value increases with an increase in SW because the expected return for the reserve fund increases, but they are almost the same for SW = 75% and 100% because of the upper limits. Even with the better economic assumption in economic assumption 3, the 50th percentile value does not attain 50%, which is the government's target.

Panel (B) illustrates the RER results for economic assumption 3. The general characteristics are similar to economic assumption 5, although the RER level tends to be higher. It should be noted that the 10th percentile value becomes one in the last year of the simulation periods for all SWs and does not reach zero, except for SW = 100%. The 90th percentile values for SW ≥ 50% increase and do not fall to one.

Figures 2 and 3 show that the RR and RER have considerable downside risks despite the existence of the ABM. We explore the main source of these fluctuations in subsection "Robustness checks" below.

Examination of joint movements of the replacement rate (RR) and reserve-to-expenditure ratio (RER). Figure 4 displays statistics that capture the joint distribution of the RR (vertical axis) and RER (horizontal axis). Panels (A) and (B) show the results of economic assumptions 5 and 3, respectively. The pink triangle, red square, and light green triangle represent the 90th, 50th, and



(A) Joint transition for economic assumption 5 **(B) Joint transition for economic assumption 3**

Fig. 4 Joint transition of percentile value and marginal conditional value at risk by year and stock weight. A Joint transition of RR and RER for economic assumption 5. **B** Joint transition of RR and RER for economic assumption 3. Pink triangles, red squares, and light green triangles represent the 90th, 50th, and 10th percentile values, respectively, and green diamonds represent the marginal CVaR (mean value of RR and RER under their 10th particle value) according to the stock weight (SW). The arrow indicates the initial value in 2019, and the opposite end indicates 2115.

10th percentile values, respectively. The 10th percentile value corresponds to this study's value at risk (VaR). A marginal conditional value at risk (CVaR) is defined as the mean of each variable (RR or RER) below its VaR. The green diamond is located at a cross point of each CVaR. The point indicated by an arrow is the year 2019, the start year of our simulation, and the opposite end is the year 2115, the last year of the simulation. In between indicates intermediate years of simulation. We use the VaR and CVaR to measure the risk of RR and RER (risk indicators). However, we cannot manage risk only by measuring risk; criteria for evaluating these indicators are needed. We use RR = 40% and RER = 0 as our criteria. The government target is RR = 50% and RER = 1. However, our results show that RR = 50% is too high to accomplish on average. Whether or not the pension reserve fund is depleted is an important political issue; we thus use RER = 0.[14]

Panel (A) displays the results for economic assumption 5. For SW (stock weight) = 0% (the upper left plot), all statistics go down and move to the left from the start to the last year of simulation, meaning that the RR and RER decrease as the simulation year increases. The 50th percentile values should be located on the vertical line of one in the last year of simulation by the ABM for all SWs.[15] For SW = 25% or more, the 10th percentile value moves to the left until the middle year of the simulation, indicating that the RER worsens. Then, towards the last year of the simulation, it moves to the right and almost reaches the vertical line of one for most SWs, which means that the RER improves. These results indicate that temporary government borrowing is possible. The borrowing can be repaid by reducing pension benefits through the ABM. The movements of CVaR are similar to the 10th percentile values, except for SW = 75% and 100%. The CVaRs move to the left towards the last year of the simulation, indicating that the CVaR of the RER worsens. The 90th percentile values for SW = 25% or more move to the right, meaning the RER improves. The 90th percentile values then move to the vertical line of one in a later simulation period because of the ABM, whereas that of SW = 100% continues to move to the right.[16]

Panel (B) displays the results for economic assumption 3. The general tendency regarding SW is similar to that of economic assumption 5, although all statistics shift upward, indicating that RR improves. It should be noted that from SW = 0% and 75%, the VaR and CVaRs are close, whereas the CVaR for SW = 100% moves in the left direction mainly because of the negative investment returns. The 90th percentile values for SW = 50% or more move in the right direction and do not turn towards the vertical line of one.[17]

Examination of the replacement rate (RR) and reserve-to-expenditure ratio (RER) specific for economic assumption 5 and year 2075. In this subsection, we choose a particular year (2075) and analyse the relationship between the RER and RR for economic assumption 5 to deepen our understanding of the effect of the SW (stock weight). Figure 5 displays the RR and RER scatter plots for economic assumption 5 in 2075. The orange dots represent the points where the RR or RER is less than the 10th percentile value (VaR), and the blue dots represent the other points. The pink triangle, red square, and light green triangle represent the 90th, 50th, and 10th percentile values, respectively. The green diamonds represent the CVaR of RR and RER.[18] Fig. 5 reveals that the scatter plot for SW = 0% has a round shape, whereas other scatter plots have a distinctive shape. The RR and RER fluctuate depending on the SW. The realised distribution is broad and distinct, narrow in the lower left, and wide in the upper right. As SW increases, the scattering becomes more extensive.

Panel (A) of Fig. 6 displays the 50th percentile value, VaR, and CVaR of the RER for economic assumption 5 in 2075. The 50th percentile value increases approximately from 1.0 to 2.0 as the SW increases, peaks at SW = 50% and 75%, and then decreases (concave shape). By contrast, the VaR is approximately 0.0 in the case of SW = 0% and 25% and then decreases. The CVaR is similar to the VaR but decreases sharply for SW = 50% or more. Panel (B) displays the 50th percentile value, VaR, and CVaR of the RR for economic assumption 5 in 2075. The 50th percentile value increases approximately from 38% to 40% as the SW increases, peaks at SW = 50% and 75%, and then decreases. By contrast, the VaR and CVaR are higher around SW = 0% and 25%, decreasing as the SW increases. Panel (C) illustrates these two probabilities. The upper line illustrates the probability that the RR is less than its VaR or the RER is less than its VaR. The probability decreases from approximately 16% to 14% as the SW increases until SW = 50%, after which it is flat for SW = 50% or more. The lower line shows the probability that the RR is less

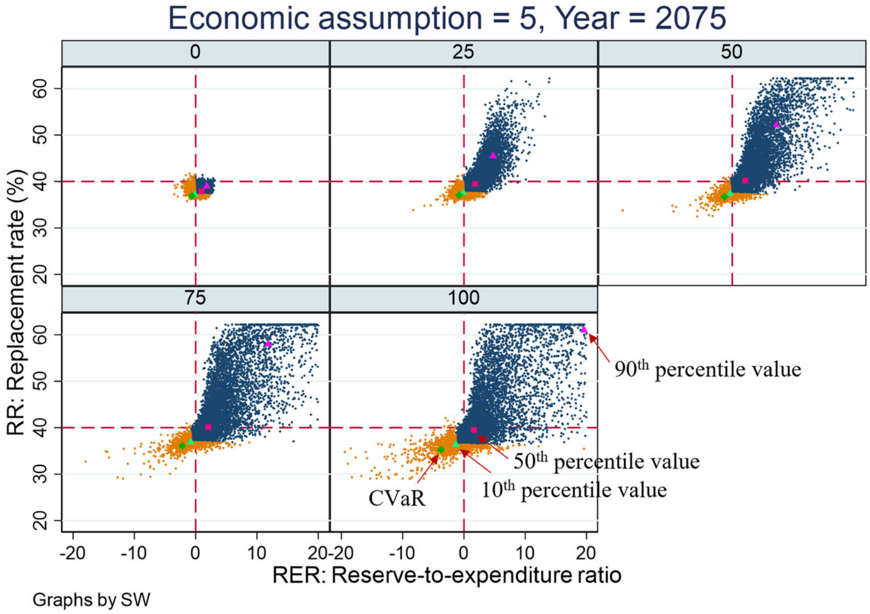


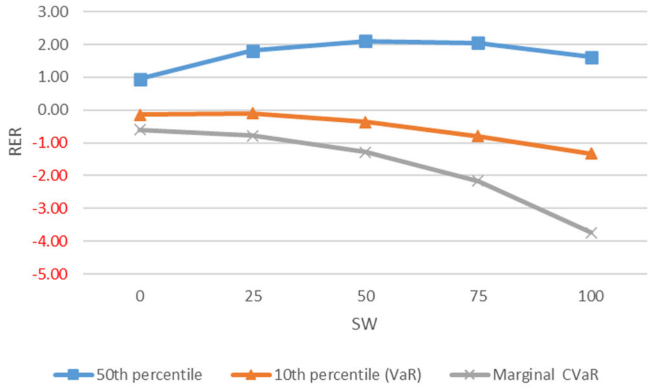
Fig. 5 Scatter plot of RR and RER for economic assumption 5 and year = 2075. The pink triangle, red square, and light green triangle represent the 90th percentile, 50th percentile, and 10th percentile values, respectively, and green diamonds represent the marginal CVaR (mean value of RR and RER under their 10th particle value) according to the stock weight (SW). The orange dots represent the RR and RER below the 10th percentile value.

than its VaR and the RER is less than its VaR, representing a more severe risk situation. The probability increases from approximately 4.0% to 6.0% as the SW increases until SW = 50%, after which it is flat for SW = 50% or more.

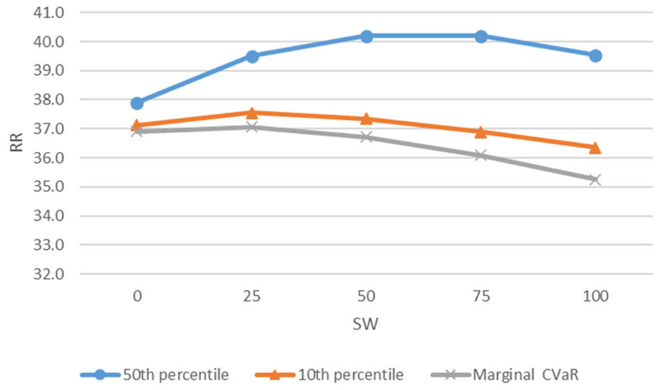
In summary, when considering the 50th percentile value, the RR and RER are jointly highest around SW = 50% and 75%. By contrast, the RR and RER are jointly stable around SW = 50% or less when considering the VaR and CVaR. The VaR and CVaR for each RR or RER continue to decrease for SW ≥ 75% or more. The probability that the RR or RER is less than its VaR is relatively flat for SW = 25%, 50%, and 75%. These results indicate that the SW should not be high or low. The following section examines these relationships for other years (2050, 2100, and 2115).

Examination of the effect of the stock weight (SW) on the replacement rate (RR) and reserve-to-expenditure ratio (RER). Table 2 summarises the results of the analysis. Panels A and B display the simulation results for economic assumptions = 5 and 3, respectively. Panel A shows that the RR (replacement rate) and RER (reserve-to-expenditure ratio) tend to have the highest values for moderate SW (stock weight), such as SW = 50% and 75%, when considering the 50th percentile values. The RR and RER tend to have the highest values for low SW, such as SW = 0% and 25%, when we focus on the risk (VaR and CVaR) in 2050, 2075, 2100, and 2115. The probability that either the RR or RER is less than its VaR is the lowest for SW = 75% in 2050 and 2075, SW = 25% in 2100, and SW = 0% in 2115. Panel B shows the results for economic assumption 3, similar to economic assumption 5; a higher SW can pursue a higher RR and RER because of the better economic conditions for economic assumption 3 than for economic assumption 5. The 50th percentile values tend to be the highest for higher SWs (SW = 75% and 100%), whereas the VaR and CVaRs tend to be the highest for lower SWs (SW = 0% and 25%). The probabilities that the RR or RER is less than its VaR have a U-shape concerning the SW, meaning that the probabilities tend to be lower for moderate SWs except for the year 2115. The SW should be determined considering risk and return. How to determine SW should be a matter of policy discussion. The current government verification uses only the median values for valuation, but discussing whether risk and return should be emphasised and how they should be valued is necessary. Based on our simulation results, moderate risk-taking, such as SW = 50%, is expected to perform better when considering the risk and return of RR and RER. However, further policy discussion is needed to determine the optimal SW, considering the timeline to assume, the economic situation, the expected RR compared to the current target (RR = 50%), and the burden on negative RER, which will be our future study.

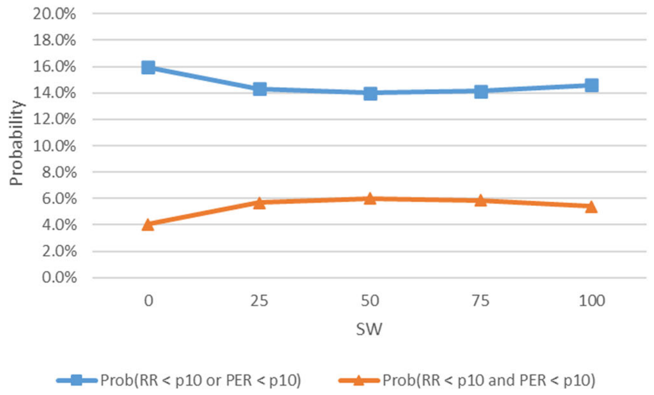
Government obligation in the case of depleted reserve funds. Figure 2 and Table 2 show that reserve funds can be depleted with certain probabilities. Once depleted, the difference between total revenue and total expenditure is expected to be covered by the government. It would be important to consider the extent to which the government will have to bear the burden of making up for this shortfall. We assess the present value of this government obligation if the RER (reserve-to-expenditure ratio) becomes negative. We estimate two measures under four different discount rates. One is the present value of the net cash flow (the difference between total revenue and total expenditure) of the public pension when RER < 0 (cashflow-based measure), and the other is the present value of the minimum reserve funds when RER < 0 (balance-based measure). The former captures the present value of total government spending to compensate for the shortfall in reserve funds, and the latter captures the present value of the maximum government debt. We use four different discount rates: the average 10-year Japanese government bond (JGB) yield (0.19%), the expected return of domestic bonds (0.49%), the inflation rate (0.80%), and the expected return of investments (2.82%). The average 10-year JGB yield is a daily average over the last 10 years (2012/12–2022/12) for 10-year maturity JGBs. The expected returns on domestic bonds, inflation rate, and the expected returns on investments use our simulation assumptions in economic assumption 5, and SW = 50%. Although the government indicates that the pension system will become a full pay-as-you-go system once the reserve fund is exhausted, we assume that ABM will continue.



(A) Reserve-to-expenditure ratio (RER) for economic assumption 5 and Year = 2075



(B) Replacement rate (RR) for economic assumption 5 and Year = 2075



(C) Probability of risk situation for economic assumption 5 and Year = 2075

Fig. 6 Simulation result for economic assumption 5 and year = 2075. A RER for economic assumption 5 and Year = 2075. **B** RR for economic assumption 5 and Year = 2075. **C** Probability of risk situation for economic assumption 5 and Year = 2075. Marginal CVaR represents the mean of a variable below the 10th percentile value. Prob (RR < p10 or PER < p10) represents the probability that the RR is less than the 10th percentile value or the RER is its 10th percentile value. Prob (RR < p10 and PER < p10) represents the probability that the RR is less than the 10th percentile value, and the RER is its 10th percentile value.

Table 3 shows the (conditional) present values of the government's obligations when the RER becomes negative, which range from JPY 9.5–65.3 trillion depending on the measures and discount rates. The probability of the RER becoming negative for at least 1 year is 20%. The results also show that the standard deviations of the two measures are large enough to indicate that the obligation could become even larger. As for the cashflow-based measure, the relationship between the discount rate and the present value is inconsistent. For example, the average value (−10.8) of the lowest discount rate (0.19%) is higher than that of the higher discount rates (0.49% and 0.80%). These results are due to the timing of the cash flows. The net cash flows tend to be negative when the RER becomes negative, and they can become positive over time as ABM reduces the benefit level. If we compare these obligations with the current outstanding face value of Japanese government bonds (JGBs), which is JPY 1027 trillion (Ministry of Finance, 2023a), the present value of government obligations is 0.9%–6.4% of the outstanding value. These amounts of government obligations are insignificant compared to the JGB, as the JGB has a huge outstanding balance. Now, comparing government obligations to GDP, the cashflow-based measure is not a considerable number. However, when looking at the balance-based measure, there is a considerable risk that the obligation becomes a significant burden (11.4% of GDP) compared to other countries (Ministry of Finance, 2023b). The obligation is lower in the cashflow-based measure than the balance-based measure, which is considered to be the effect of ABM reducing benefits.

Robustness checks. In the previous subsections, we noted that the RR (replacement rate) and RER (reserve-to-expenditure ratio) show significant downside risks despite the existence of ABM. Instead, ABM seems to amplify the risk of RR and RER. If the year in which ABM ends fluctuates, RR and RER also fluctuate, as explained in section "Simulation method and assumption". In addition, the fluctuations of RER and RR are also influenced by the stochastic behaviour of the inflation rate, wage growth rate, and investment returns. The question naturally arises as to which factor contributes most to the fluctuations in RER and RR. Therefore, we ran additional simulations to investigate the source of volatility in RER and RR by varying only one variable and fixing the others at their mean.

Columns (2)–(4) in Table 4 show the results when only one variable is stochastic under economic assumption 5 and SW = 50%. Column (1) again shows that the results for all three variables are stochastic, with SW = 50% as the reference (referred to as the base case). The column of the government verification displays that all our stochastic variables are fixed at their means, which mimics the MHLW (2019b) through our simulation. The 50th percentile values of RR and RER in Column (1) are lower than those of the government verification because investment returns are low in some cases, and modified indexation continues

Table 2 Simulation results. Panel A: Simulation results for economic assumption 5. Panel B: Simulation results for economic assumption 3.

Stock weight (SW)		0	25	50	75	100
Panel A-(1): Economic assumption 5, year = 2050						
RR	90th percentile	46.7	48.7	52.2	57.9	61.0
	50th percentile	45.2	46.3	46.7	46.7	46.4
	10th percentile (VaR)	44.2	44.7	44.6	44.2	43.8
	Marginal CVaR	44.0	44.3	44.1	43.6	43.1
RER	90th percentile	2.60	5.55	7.74	10.79	15.13
	50th percentile	1.92	2.80	3.12	3.12	2.89
	10th percentile (VaR)	1.19	1.07	0.75	0.31	−0.13
	Marginal CVaR	0.88	0.59	0.19	−0.31	−0.85
Prob (RR < p10 or RER < p10)		19.3%	17.5%	16.7%	16.5%	16.8%
Prob (RR < p10 and RER < p10)		0.7%	2.5%	3.3%	3.5%	3.2%
Panel A-(2): Economic assumption 5, year = 2075						
RR	90th percentile	39.0	45.5	52.2	57.9	61.0
	50th percentile	37.9	39.5	40.2	40.2	39.5
	10th percentile (VaR)	37.1	37.5	37.3	36.9	36.4
	Marginal CVaR	36.9	37.1	36.7	36.1	35.3
RER	90th percentile	1.82	4.75	7.21	11.85	19.60
	50th percentile	0.95	1.82	2.11	2.04	1.62
	10th percentile (VaR)	−0.14	−0.10	−0.36	−0.79	−1.33
	Marginal CVaR	−0.61	−0.79	−1.28	−2.16	−3.74
Prob (RR < p10 or RER < p10)		18.5%	15.5%	14.7%	14.6%	14.7%
Prob (RR < p10 and RER < p10)		1.5%	4.5%	5.3%	5.4%	5.3%
Panel A-(3): Economic assumption 5, year = 2100						
RR	90th percentile	38.5	45.5	52.2	57.9	61.0
	50th percentile	36.7	38.6	39.3	39.0	37.9
	10th percentile (VaR)	33.3	32.9	32.6	32.1	31.5
	Marginal CVaR	32.5	32.1	31.6	30.9	29.9
RER	90th percentile	1.41	2.71	3.94	8.12	18.11
	50th percentile	0.93	1.30	1.42	1.36	1.12
	10th percentile (VaR)	0.16	−0.01	−0.29	−0.76	−1.42
	Marginal CVaR	−0.24	−0.59	−1.26	−3.03	−8.11
Prob (RR < p10 or RER < p10)		13.0%	12.7%	12.8%	13.3%	13.7%
Prob (RR < p10 and RER < p10)		7.0%	7.3%	7.2%	6.7%	6.3%
Panel A-(4): Economic assumption 5, year = 2115						
RR	90th percentile	38.5	45.5	52.2	57.9	61.0
	50th percentile	36.7	38.6	39.3	39.0	37.9
	10th percentile (VaR)	32.5	30.7	30.2	29.7	29.2
	Marginal CVaR	30.3	29.7	29.2	28.4	27.3
RER	90th percentile	1.00	1.00	1.00	5.17	17.68
	50th percentile	1.00	1.00	1.00	1.00	1.00
	10th percentile (VaR)	1.00	0.89	0.67	0.24	−0.45
	Marginal CVaR	0.92	0.58	−0.30	−3.28	−13.13
Prob (RR < p10 or RER < p10)		10.0%	13.9%	15.0%	15.4%	15.5%
Prob (RR < p10 and RER < p10)		7.4%	6.1%	5.0%	4.6%	4.5%
Panel B-(1): Economic assumption 3, year = 2050						
RR	90th percentile	46.2	49.6	57.0	62.2	62.2
	50th percentile	45.6	47.4	48.4	49.1	49.3
	10th percentile	45.2	46.0	46.2	46.0	45.5
	Marginal CVaR	45.0	45.6	45.6	45.3	44.8
RER	90th percentile	3.13	6.42	8.96	13.56	20.79
	50th percentile	2.59	3.77	4.32	4.75	5.02
	10th percentile (VaR)	2.04	2.03	1.76	1.36	0.98
	Marginal CVaR	1.84	1.61	1.28	0.89	0.53
Prob (RR < p10 or RER < p10)		18.4%	17.5%	17.3%	17.1%	17.2%
Prob (RR p10 and RER < p10)		1.6%	2.5%	2.7%	2.9%	2.8%
Panel B-(2): Economic assumption 3, year = 2075						
RR	90th percentile	40.5	49.3	57.0	62.2	62.2
	50th percentile	39.7	43.3	45.8	47.2	47.0
	10th percentile	38.7	39.8	39.9	39.6	39.1
	Marginal CVaR	38.3	39.2	39.2	38.8	38.2
RER	90th percentile	2.47	5.68	10.05	22.38	47.32
	50th percentile	1.92	3.09	3.57	3.99	4.17
	10th percentile (VaR)	1.34	1.43	1.15	0.69	0.29

Table 2 (continued)

	Marginal CVaR	1.08	0.93	0.56	0.11	−0.38
Prob (RR < p10 or RER < p10)		16.0%	14.3%	14.0%	14.1%	14.6%
Prob (RR < p10 and RER < p10)		4.0%	5.7%	6.0%	5.9%	5.4%
Panel B-(3): Economic assumption 3, year = 2100						
RR	90th percentile	40.5	49.3	57.0	62.2	62.2
	50th percentile	39.7	43.3	45.8	47.2	47.0
	10th percentile	38.7	39.5	38.7	36.5	35.4
	Marginal CVaR	38.2	37.8	36.2	34.8	34.1
RER	90th percentile	1.66	3.15	9.52	39.35	109.23
	50th percentile	1.35	1.94	2.23	2.50	2.63
	10th percentile (VaR)	1.03	1.08	0.88	0.52	0.15
	Marginal CVaR	0.90	0.78	0.43	−0.28	−2.06
Prob (RR < p10 or RER < p10)		16.4%	14.9%	13.7%	12.9%	13.1%
Prob (RR < p10 and RER < p10)		3.6%	5.1%	6.3%	7.1%	6.9%
Panel B-(4): Economic assumption 3, year = 2115						
RR	90th percentile	40.5	49.3	57.0	62.2	62.2
	50th percentile	39.7	43.3	45.8	47.2	47.0
	10th percentile	38.7	39.5	38.7	35.2	33.4
	Marginal CVaR	38.2	37.6	35.0	32.7	31.8
RER	90th percentile	1.00	1.00	9.45	57.53	179.45
	50th percentile	1.00	1.00	1.00	1.00	1.00
	10th percentile (VaR)	1.00	1.00	1.00	1.00	0.73
	Marginal CVaR	.	0.85	0.53	−0.34	−3.86
Prob (RR < p10 or RER < p10)		10.0%	10.0%	10.0%	10.1%	12.8%
Prob (RR < p10 and RER < p10)		0.0%	0.8%	4.5%	9.0%	7.2%

Notes: RR and RER represent the replacement rate and reserve-to-expenditure ratio, respectively. The marginal CVaR represents the mean of a variable below its 10th percentile value. Prob (RR < p10 or PER < p10) represents the probability that the RR is less than the 10th percentile value or the RER is its 10th percentile value. Prob (RR < p10 and PER < p10) represents the probability that the RR is less than the 10th percentile value, and the RER is its 10th percentile value. Each value is estimated based on a Monte Carlo simulation with 9000 replications.

Table 3 Present value of government obligation when reserve funds are depleted.

Discount rate		Present value of net cash flow of total public pension when RER < 0: Avg. (Std.)	Percentage of outstanding JGBs	Percentage of GDP	Present value of minimum reserve fund when RER < 0: Avg. (std.)	Percentage of outstanding JGBs	Percentage of GDP
0.19%	Average 10 years JGB yield	−10.8 (67.1)	1.0%	1.9%	−65.3 (89.1)	6.4%	11.4%
0.49%	Expected return of domestic bonds	−12.3 (55.4)	1.2%	2.1%	−53.3 (70.5)	5.2%	9.3%
0.80%	Inflation rate	−13.0 (46.0)	1.3%	2.3%	−43.3 (55.7)	4.2%	7.6%
2.82%	Expected return of investments	−9.5 (17.6)	0.9%	1.7%	−11.8 (14.3)	1.1%	2.1%
Number of samples when RER < 0		1799					
Percentage of total number of simulations		20.0%					

Note: The unit is JPY trillion. Average 10 years JGB yield is a daily average of 10-year maturity Japanese Government Bond (JGB) yields for the last 10 years (2012/12–2022/12). The expected return of domestic bonds, inflation rate, and expected return of investments are assumptions under economic assumption 5 and stock weight = 50%. The total outstanding face value of JGBs is JPY 1,027 trillion in 2023 (Ministry of Finance, 2023a). The predicted gross domestic product (GDP) is JPY 572 trillion in 2023. The percentage of outstanding JGBs represents a share of the (negative) average present value of government obligation relative to the outstanding face value of JGB. The percentage of GDP represents a share of the (negative) average present value of government obligation relative to the GDP.

(modified indexation does not end during our simulation for some paths, as explained in subsection "Transitions of marginal distribution for the replacement rate (RR) and reserve-to-expenditure ratio (RER)").

Column (2), where only investment returns are stochastic, shows the result close to the base case in Column (1). In Columns (3) and (4), the variations of RR and RER for the results in which the stochastic variable is only wage growth rate or inflation rate are small. The results suggest that the volatility of investment returns mainly explains the variations in RR and RER. The results in Columns (3) and (4) are close to those of the government verification (which has no variation): Wage growth rate and inflation rate have less impact on the variations of RR and RER than investment returns. These results are consistent with previous studies (Kitamura et al., 2006; MHLW, 2020b).

Furthermore, the literature shows that the volatilities of economic variables change over time. The volatility of many economic variables increases during recessions, and in particular, stock volatility increases when stock prices fall and debt rises (Schwert, 1989). A US study also shows that the volatility of GDP, macroeconomic, and financial variables decreased significantly after the mid-1980s (Justiniano and Primiceri, 2008), referred to

Table 4 Robustness checks.

Year	Variable	Government verification	Percentile	(1) Stock weight = 50%	(2) Inv. return only	(3) Wage rate only	(4) Inflation only	(5) Volatility doubled	(6) Volatility halved	(7) Foreign 100%	(8) Domestic 100%
2050	RR		90th percentile	52.2	52.0	49.7	48.0	48.9	50.6	56.4	49.4
		47.1	50th percentile	46.7	45.8	48.1	47.4	44.7	47.7	46.6	46.2
			10th percentile	44.6	44.2	47.1	46.8	43.0	46.0	44.2	44.4
	RER		90th percentile	7.7	7.6	4.4	4.3	10.7	5.9	10.2	6.7
		4.0	50th percentile	3.1	3.1	4.0	4.0	1.1	3.7	3.0	2.7
			10th percentile	0.7	0.9	3.4	3.7	−0.6	2.1	0.3	0.6
2075	RR		90th percentile	52.2	52.0	45.8	45.5	46.2	50.0	56.4	47.7
		44.5	50th percentile	40.2	40.0	44.4	44.6	37.4	43.0	39.9	39.2
			10th percentile	37.3	37.1	41.8	43.7	35.6	39.0	36.9	37.1
	RER		90th percentile	7.2	7.0	3.8	3.8	9.1	5.2	10.6	5.8
		3.4	50th percentile	2.1	2.2	3.3	3.4	0.3	3.0	1.9	1.6
			10th percentile	−0.4	−0.0	2.5	3.1	−1.8	1.0	−0.8	−0.5
2100	RR		90th percentile	52.2	52.0	45.8	45.5	46.1	50.0	56.4	47.7
		44.5	50th percentile	39.3	39.7	44.4	44.6	35.9	42.9	38.6	38.0
			10th percentile	32.6	32.9	41.0	43.7	31.1	34.9	32.1	32.4
	RER		90th percentile	3.9	3.8	2.5	2.5	4.3	3.1	6.4	3.2
		2.2	50th percentile	1.4	1.5	2.1	2.2	0.6	2.0	1.3	1.2
			10th percentile	−0.3	0.1	1.7	2.0	−1.0	0.7	−0.7	−0.3
2115	RR		90th percentile	52.2	52.0	45.8	45.5	46.1	50.0	56.4	47.7
		44.5	50th percentile	39.3	39.7	44.4	44.6	35.8	42.9	38.6	38.0
			10th percentile	30.2	30.8	41.0	43.7	28.9	33.2	29.7	30.1
	RER		90th percentile	1.0	1.0	1.0	1.0	1.0	1.0	2.1	1.0
		1.0	50th percentile	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
			10th percentile	0.7	0.9	1.0	1.0	0.5	1.0	0.3	0.8

Notes: RR and RER represent the replacement rate and reserve-to-expenditure ratio, respectively. Stock weight = 50 redisplays the results in Panel A of Table 2 for stock weight = 50%. Inv. return only, wage only, and inflation only represent that the stochastic variable is only investment return, wage growth rate, and inflation, respectively. Foreign 100% and domestic 100% represent that investments are only in foreign and domestic assets, respectively. All simulations are under economic assumption 5 and stock weight = 50%.

as the great modification. The literature has discussed factors for this phenomenon, including simple luck, monetary policy, and inventory management. Recent market integration causes a phenomenon in one market to spill over to another (Engle and Susmel, 1993): Changes in volatility in the US can lead to changes in volatility in other markets, including Japan (Schwert, 2011). Our simulation uses the volatility assumptions estimated from the last 25 years of data (1993–2017), which is after the great modification, and the volatilities happen to be low: the future volatilities may be higher or lower than in the past. To further check the robustness of our results, we run additional simulations with double and half the volatility of investment returns: all asset class volatilities are doubled (halved), and the volatility is estimated for SW = 50%. We keep the same assumptions for the expected returns and correlations. Columns (5) and (6) in Table 4 show the simulation results for doubling and halving the volatility of the asset classes. We calculate the investment returns based on SW = 50% under economic assumption 5. As expected, fluctuations of RR and RER are larger in Column (5) than in Column (6). However, the results in Columns (5) and (6) are not uniformly worsened or improved compared with the base case. For the doubled volatilities, RR and RER are worsened except for the 90th percentile values of RER. For the halved volatilities, RR and RER are improved except for the 90th percentile values of RR and RER. These results indicate that the effect of volatility is not simple: asset volatility assumption is one of the critical factors regarding fluctuations of RR and RER because of the ABM.

Finally, in our simulation, we assume that domestic and foreign stocks (bonds) are equally weighted for each different SW. However, the variations in RR and RER may be sensitive to the allocation of domestic and foreign assets because the impact of economic assumptions about exchange rates, interest rates, and economic growth differs between foreign and Japanese markets. To examine the effect of allocation to foreign assets on the variation of RR and RER, we run additional simulations for two polar cases: foreign-only or domestic-only allocation. For the foreign-only, stocks are allocated to foreign stocks and bonds to foreign bonds. The domestic-only allocation is similar. We then simulate these polar cases under SW = 50% and economic assumption 5 to compare the results with the base case: The allocation of the foreign-only is that foreign stocks are 50% and foreign bonds are 50%. Because of these changes in allocation, the assumptions on the expected returns, risk, and correlations between investment returns, inflation rate, and wage growth rate differ from the base case. Columns (7) and (8) in Table 4 display the results for foreign-only and domestic-only allocation, respectively. The results show that RR and RER tend to be lower than the base case. The values of RR and RER for the domestic-only are lower than those of the base case, partly because the domestic-only has lower expected returns. There are notable differences for the foreign-only in Column (7). The 10th percentile values of RER are distinctly lower than that of the base case, indicating that the allocation only to foreign assets is risker than the base case. By contrast, the 90th percentile values of RER are higher than those of the base case because of the higher expected returns for foreign allocation only. These results indicate that a certain level of mixing asset classes with domestic and foreign assets is preferable to the polar cases by diversifying risks and maintaining expected returns. However, we only examine the two polar cases and do not address the other allocations. There may be more efficient allocations between domestic and foreign investments, and further research is needed, which will be future work.

Dynamic investment strategies. In the previous sections, the SW (stock weight) was fixed (a constant mix strategy) during the simulation period. However, SW need not be constant and can be changed dynamically according to investment objectives (Perold and Sharpe, 1988; Sharpe, 1987). In this subsection, we consider two dynamic investment strategies to examine their effectiveness in controlling the downside risk of RR (replacement rate) and RER (reserve-to-expenditure ratio): portfolio insurance and contrarian strategy.

Portfolio insurance is a risk management strategy to protect the downside risk of a portfolio while maintaining the return potential. Various methods and strategies to secure risky assets against large losses can be found in the literature, such as the stop-loss strategy (Bird et al., 1988), the synthetic put strategy (Rubinstein and Leland, 1981), the constant proportion portfolio insurance (CPPI) strategy (Black and Jones, 1987; Black and Perold, 1992), the time-invariant portfolio protection methodology (Estep and Kritzman, 1988), and the VaR dynamic investment strategy (Herold et al., 2007). In general, to maintain a predetermined floor, the SW decreases when the stock price falls to avoid further losses. By contrast, it increases when the stock price rises due to the increased risk buffer.

The literature analyses the performance of portfolio insurance. Cesari and Cremonini (2003) show that the performance of portfolio insurance depends on the market environment. For example, the constant proportion portfolio insurance strategy dominates other strategies in bear and no-trend markets, while a constant mix strategy is preferred in bull markets. Annaert et al. (2009) find that portfolio insurance strategies outperform a buy-and-hold strategy regarding downside protection but provide lower excess returns. They argue that portfolio insurance strategies are a valuable alternative to fixed strategies for investors considering downside protection.

Previous studies also analyse the investors' suitability of portfolio insurance for investors. Dichtl and Drobetz (2011) analyse portfolio insurance in the context of cumulative prospect theory and suggest that loss aversion and probability weighting contribute to portfolio insurance being a preferred investment strategy for a prospect theory investor. Dierkes et al. (2010) also demonstrate that portfolio insurance is attractive to investors with preferences described by cumulative prospect theory. Institutional investors often use portfolio insurance to protect their portfolios from large losses. Shefrin and Statman (1993) and Kahneman and Riepe (1998) argue that investment advisors should consider strategies limiting the downside risk while retaining some possible upside gains. A major drawback of portfolio insurance is the cost of buying derivatives or managing option duplicating portfolios. In addition, protection may not be perfect: changing market conditions and discrete transactions incur additional risk to keep the floor.

A contrarian strategy, in general, is formed by buying past losers and selling past winners (De Bondt and Thaler, 1985, 1987). A contrarian strategy is profitable by exploiting investors' suboptimal behaviour, such as overreaction. Various variables have been used to construct contrarian portfolios, including past stock returns (De Bondt and Thaler, 1985) and accounting ratios such as book-to-market, cash flow-to-price and earnings-to-price (Lakonishok et al., 1994). Studies have demonstrated the profitability of contrarian strategies in various countries and regions, including European countries (Brouwer et al., 1997; Mun et al., 1999), China (Kang et al., 2002; Chen et al., 2018), New Zealand (Chin et al., 2002), Turkey (Bildik and Gülay, 2007), Hong Kong (Ramiah et al., 2011), and Japan (Chou et al., 2007). The contrarian strategy is utilised by institutional investors such as pension funds, life insurance companies, and mutual funds (De Haan and Kakes, 2011; Wei et al., 2015). Although the contrarian strategy originally aimed to exploit market inefficiencies and generate profits, this study examines the rule-based contrarian strategy to compare it with portfolio insurance. Since this study uses simulations and not market data, we analyse the impact of a rule-based contrarian strategy on the downside risk of RR and RER.

This section presents an application example for portfolio insurance and a contrarian strategy for RER under an ABM. The RER represents the long-term sustainability of the public pension system and the target of the ABM. We then compare the effect of these strategies with the constant mix strategy (SW = 50%) for RER and RR risk management. Table 5 displays the SW change rules based on portfolio insurance and (rule-based) contrarian strategy. We focus on RER instead of the value of reserve funds to decide on a stock allocation: For example, SW = 25% in portfolio insurance if $3.5 > RER \geq 2.5$, whereas SW = 75% in the contrarian strategy for the same RER range. We apply this rule in 2040, 2060, 2080, and 2100 only for paths in which the ABM does not stop (financial equilibrium is not attained). We retain the previous year's SW for paths in which the ABM stops. In addition, we do not control the RR, as the ABM does not control it.[19] We assume that the inflation rate, wage growth rate, and investment returns follow a random walk. In this sense, these stochastic variations do not work to the advantage or disadvantage of portfolio insurance and the contrarian strategy, but the characteristics of the strategies (the rules for changing the SW shown in Table 5) determine the impact of each strategy on the RR and RER.[20] We run a Monte Carlo simulation with 9000 replications, similar to our main analysis.

Table 5 Stock weight for portfolio insurance and contrarian strategies.

Stock weight (SW)	Condition for RER: Portfolio insurance	Contrarian strategy
100	RER ≧ 5.5	2.5 > RER
75	5.5 > RER ≧ 4.5	3.5 > RER ≧ 2.5
50	4.5 > RER ≧ 3.5	4.5 > RER ≧ 3.5
25	3.5 > RER ≧ 2.5	5.5 > RER ≧ 4.5
0	2.5 > RER	RER ≧ 5.5

Notes: RER represents the reserve-to-expenditure ratio. Based on the condition of RER, stock weight (SW) for each path changes in 2040, 2060, 2080, and 2100 for paths where the ABM does not stop (financial equilibrium is not attained). The previous year's stock weight is maintained for paths where the ABM stops.

Table 6 presents the simulation results for the portfolio insurance and the contrarian strategy. We include the results of SW = 50% (referred to as the base case) for reference and display the same statistics for RR and RER in 2050, 2075, 2100, and 2115 from Panel A of Table 2. The results reveal that portfolio insurance allows us to control RR and RER risks while giving up on attaining the median values of the base case. The VaR and CVaR in the portfolio insurance are higher than in the base case as the year gets later, indicating that the portfolio insurance can successfully manage the downside risks of RER and RR. The 90th percentile values for RR and RER are also higher than in the base case. By contrast, the 50th percentile values are lower than in the base case. The contrarian strategy leads to opposite results. It can

Table 6 Simulation results for dynamic investment strategies.

		Year = 2050: SW = 50%	Portfolio insurance	Contrarian strategy	Year = 2075: SW = 50%	Portfolio insurance	Contrarian strategy
RR	90th percentile	52.2	53.2	51.0	52.2	53.2	49.7
	50th percentile	46.7	46.0	46.6	40.2	39.0	40.6
	10th percentile (VaR)	44.6	44.3	44.4	37.3	37.1	37.1
	Marginal CVaR	44.1	43.9	43.8	36.7	36.8	36.4
RER	90th percentile	7.74	8.21	7.37	7.21	7.82	6.56
	50th percentile	3.12	2.87	3.39	2.11	1.74	2.59
	10th percentile (VaR)	0.75	0.75	0.60	−0.36	−0.30	−0.45
	Marginal CVaR	0.19	0.20	0.05	−1.28	−1.00	−1.82
Prob (RR < p10 or RER < p10)		16.7%	17.8%	16.5%	14.7%	16.3%	15.1%
Prob (RR < p10 and RER < p10)		3.3%	2.2%	3.5%	5.3%	3.7%	4.9%
		Year = 2100			Year = 2115		
RR	90th percentile	52.2	53.2	49.7	52.2	53.2	49.7
	50th percentile	39.3	38.3	39.8	39.3	38.3	39.8
	10th percentile (VaR)	32.6	33.3	32.8	30.2	32.9	30.6
	Marginal CVaR	31.6	32.2	31.6	29.2	30.3	29.2
RER	90th percentile	3.94	4.25	3.64	1.00	1.00	1.00
	50th percentile	1.42	1.24	1.56	1.00	1.00	1.00
	10th percentile (VaR)	−0.29	0.17	−0.15	0.67	1.00	0.77
	Marginal CVaR	−1.26	−0.35	−1.36	−0.30	0.91	−0.09
Prob (RR < p10 or RER < p10)		12.8%	12.3%	12.3%	15.0%	10.0%	14.6%
Prob (RR < p10 and RER < p10)		7.2%	7.7%	7.7%	5.0%	6.7%	5.4%

Notes: RR and RER represent the replacement rate and reserve-to-expenditure ratio, respectively. VaR represents the value-at-risk. The marginal CVaR (conditional VaR) is defined by the mean of a variable below its 10th percentile value. Prob (RR < p10 or PER < p10) represents the probability that the RR is less than the 10th percentile value or the RER is its 10th percentile value. Prob (RR < p10 and PER < p10) represents the probability that the RR is less than the 10th percentile value, and the RER is its 10th percentile value. SW = 50% indicates that the stock weight (SW) is fixed at 50% during the simulation (the values are the same as in Table 2). As shown in Table 3, for the portfolio insurance, SW decreases as RER decreases, while SW increases as RER increases. For the contrarian strategy, SW increases as RER decreases, while SW decreases as RER increases. Each value is estimated based on a Monte Carlo simulation with 9000 replications. The results are based on economic assumption 5.

achieve higher median values for the RER and RR, whereas the downside risk increases.

The results indicate that portfolio insurance lowers the downside risk of the RER and RR, and, therefore, it is a candidate strategy for achieving long-term stability in public pensions. However, there are also problems with the introduction of portfolio insurance: The size of the reserve funds of the Japanese public pension system is enormous. To avoid downside risk in adverse market conditions, portfolio insurance for such large public pension funds could accelerate the destabilisation of capital markets. One example of portfolio insurance damaging stock markets is the 1987 stock market crash, Black Monday. Investors with portfolio insurance contributed to large market decline (Leland and Rubinstein, 1988): When stock prices fell sharply, investors with portfolio insurance began to sell their holdings to limit their losses. These sales accelerate the further decline in stock prices. Instead, the public pension reserve fund is expected to be a contrarian in such an unfavourable situation and stabilise the market. This study assumes that the investment behaviour of the public pension fund does not influence stock prices: the effects of the use of dynamic strategies by large public pension funds are not fully considered. Whether portfolio insurance, a contrarian strategy, or a constant mix strategy is appropriate for investing in public pensions in Japan needs further discussion. Moreover, the dynamic strategy considered in this subsection involves a change in stock weighting every 20 years, and we examine only one example of an application for portfolio insurance and the contrarian strategy. In the future, we would like to discuss which rule is more desirable for managing the downside risks of RR and RER through these strategies.

Conclusions

Using the stochastic simulation method and applying the government's verification programme for public pensions, we examine the effect of stock investments on the RR (replacement rate) and RER (reserve-to-expenditure ratio). We find that, first, the 50th percentile values of the RR for any SW (stock weight) are below 50%, which indicates that the simple scenario-based prediction the government uses overestimates the RR. Second, the risk and return of RR and RER depend on the SW. The analysis considering the SW and ABM (automatic balancing mechanism) also increases complexity. A higher SW can pursue a higher RR and RER, on average. However, as SW increases, sample paths for which the ABM does not stop during the simulation periods increase. The VaR and CVaR for the RER can fall below zero, especially for SW = 75% or more. By contrast, for SW = 0% (domestic bonds only), the 50th percentile of the RR is lower because the investment return is insufficient. As for the desirable SW considering the risk and return of the RR and RER, moderate risk-taking around SW = 50% and 75% provides the highest 50th percentile values for the RR and RER. The VaR and CVaR for RR and RER are the permissible values compared to the other SWs. Therefore, the moderate risk-taking of the reserve funds should be appropriate by accepting certain severe risk situations that may occur: The probability of both RR and RER being below their VaR remains at 5%. Third, our results show that there is a certain probability that the pension reserve fund may be depleted, and the government's obligation to compensate for the shortage of reserve funds may be a significant burden in some cases. Fourth, portfolio insurance can limit the downside risks of RR and RER, while a contrarian strategy increases the median value of RR and RER. However, determining the appropriate level of the SW, considering the risk and return of the RR and RER, is not a simple process. This study assumes that the reserve fund takes a short position with a predetermined SW when it is exhausted. According to the MHLW (2020a), "a situation in which the reserve fund is exhausted and hinders the payment of benefits should not exist even temporarily." However, we assume that the ABM continues borrowing when the reserve fund is exhausted. Our results reveal that the RER recovers to zero in many cases and often reaches one in the final year, even when it temporarily falls below zero. Currently, the government is considering switching the public pension system to a full pay-as-you-go system once the pension reserve funds are depleted. This will lead to an immediate and substantial decline in the RR. Our findings suggest that this situation could become a reality in the near future. Therefore, the government should consider borrowing to delay the system's transition.[21]

Data availability

The datasets generated and analysed during the current study are available from the corresponding author upon reasonable request.

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Notes

1 In Japan, one in three people receives a public pension. Public pensions account for approximately 70% of the income of older households. Half of older households rely only on public pension benefits as their only source of income (MHLW, 2020a, p. 10).
2 In Japan, non-payment of mandatory national pension contributions has become a problem due to the uncertainty of future pension payments for younger generations.
3 According to the OECD (2021a, 2021b), ABMs in pension systems have existed since the 1930s, initially for pension indexation: increasing pensions automatically in line with the price or wage increases to sustain pension adequacy levels. Currently, about two-thirds of OECD countries have at least one ABM feature. Mechanisms include those embodied in notional defined contribution schemes (six countries); links to the statutory retirement age to life expectancy (seven countries); benefit adjustments to changes in life expectancy, demographic ratios, or the wage bill (six countries); and balancing mechanisms (seven countries).
4 Details of the Japanese public pension system and its reforms are explained by Sakamoto (2005, 2008).
5 Early examples include Lee and Tuljapurkar (1998) and the Congressional Budget Office (2001).
6 The medium variant of the population projections assumes that the total fertility rate decreases from 1.45 in 2015 to 1.44 after 2065. It also assumes that life expectancy at birth rises from 80.75 in 2015 to 84.95 after 2065 for males (86.99 to 91.35 for females). The real economic growth rate of EA3 and EA5 assumes 0.4% and 0.0% in 20–30 years from 2029, respectively. Details are in MHLW (2019b, pp. 21–24).
7 The MHLW's simulation source codes are available at https://www.mhlw.go.jp/stf/seisakunitsuite/bunya/nenkin/nenkin/zaisei-kensyo/index.html
8 For the employees' pension insurance, sample paths where the ABM does not stop during our simulation period are almost zero for any stock weight. Therefore, the pension benefit reduction is due to the continuing ABM in the basic pension.
9 Under Japan's current public pension system, there is no discussion of what happens if the financial condition improves in the long-term. If the balance of income and payments (net cash flows) improves, the extent to which the reserve funds will increase has not been determined. In other words, instead of increasing reserve funds, whether RR rises, pension premiums decrease, and government spending is lowered has not been explicitly discussed. In our simulation, if revenues exceed expenditures, namely, if the financial position improves, there is no mechanism to increase the RR, and as a result, the reserve fund increases.
10 The pension reserve funds for both the basic pension and employees' pension insurance are considered.
11 The ABM for the basic pension and employees' pension insurance is implemented independently. Therefore, the timing of ABM termination (t_h^* may differ).
12 $\min(\delta - \gamma, 0)$ in Equation (1) is predetermined.
13 For the employee's pension insurance, these sample paths are nearly 0% for all stock weights.
14 Risk indicators can be standardised among many countries; however, risk criteria should differ in each country.
15 The vertical line of one is not shown in the Figures. Instead, the vertical line of zero is displayed to analyse the depletion of the reserve fund.
16 Animation for the scatter plots [related to Figs. 4(A) and 5] from 2019 to 2115 for economic assumption 5 is available in Supplementary Fig. S1 online.

17 In Supplementary Fig. S2 online, similar amination for economic assumption 3 is available.
18 In Fig. 5, the 90th, 50th, and 10th percentile values and CVaR were calculated separately from 2019 to 2115 and displayed in one graph.
19 We acknowledge that keeping the floor of portfolio insurance (RER = 2.5) is not attained because the portfolio insurance rules are applied discretely (every 20 years), and the RER is determined by investment returns and other stochastic variables. Thus, the RER can be below the floor.
20 For example, a contrarian may be preferable if investment returns follow a mean reverting process. However, we assume that they follow a random walk; no advantage is given to a specific strategy. In addition, we assume the asset volatilities are constant. This assumption may affect the evaluation of portfolio insurance and contrarian strategy. These effects are deferred to our future studies.
21 As the MHLW's financial verification includes cases where the RER decreases close to zero during the verification periods and then recovers to one in the final year. Discussions of the borrowing case should be included in the following verification.

References

American Academy of Actuaries (2011) Automatic adjustments to maintain social security's long-range actuarial balance. American Academy of Actuaries issue brief. https://www.actuary.org/sites/default/files/files/publications/IB_Auto_Adjustments_FINAL.pdf. Accessed 30 Apr 2023

Annaert J, Van Osselaer SV, Verstraete B (2009) Performance evaluation of portfolio insurance strategies using stochastic dominance criteria. J Bank Financ 33(2):272–280. https://doi.org/10.1016/j.jbankfin.2008.08.002. Accessed 30 Apr 2023

Arnott RD, Chaves DB (2012) Demographic changes, financial markets, and the economy. F Anal J 68(1):23–46

Besley T, Prat A (2005) Credible pensions. Fisc Stud 26(1):119–135. https://doi.org/10.1111/j.1475-5890.2005.00006.x. Accessed 30 Apr 2023

Bildik R, Gülay G (2007) Profitability of contrarian strategies: evidence from the Istanbul stock exchange. Int Rev Finance 7(1–2):61–87

Bird R, Dennis D, Tippett M (1988) A stop loss approach to portfolio insurance. J Portf Manag 15(1):35

Black F, Jones RW (1987) Simplifying portfolio insurance. J Portf Manag 14(1):48

Black F, Perold A (1992) Theory of constant proportion portfolio insurance. J Econ Dyn Control 16(3–4):403–426

Boado-Penas MDC, Godínez-Olivares H, Haberman S et al. (2020) Automatic balancing mechanisms for mixed pension systems under different investment strategies. Eur J Finance 26(2–3):277–294. https://doi.org/10.1080/1351847X.2019.1647260

Board of Trustees, Federal Old-Age and Survivors Insurance and Federal Disability Insurance Trust Funds (2020) The 2020 annual report of the board of trustees of the federal old-age and survivors insurance and federal disability insurance trust funds. https://www.ssa.gov/OACT/TR/2020/ Accessed 30 Apr 2023

Brouwer I, van der Put J, Veld C (1997) Contrarian investment strategies in a European context. J Bus Finance Account 24(9–10):1353–1366

Cabinet Office (2019) Economic and fiscal projections for medium to long term analysis Accessed July 31, 2019. https://www5.cao.go.jp/keizai3/econome/projection201907.pdf Accessed 30 Apr 2023

Castañeda P, Castro R, Fajnzylber E, Medina JP, Villatoro F (2021) Saving for the future: evaluating the sustainability and design of Pension Reserve Funds. Pac Basin Finance J 68:101335. https://doi.org/10.1016/j.pacfin.2020.101335

Cesari R, Cremonini D (2003) Benchmarking, portfolio insurance and technical analysis: a Monte Carlo comparison of dynamic strategies of asset allocation. J Econ Dyn Control 27(6):987–1011

Chen G, Matkin DST (2017) Actuarial inputs and the valuation of public pension liabilities and contribution requirements: a simulation approach. Public Budg Finance 37(1):68–87. https://doi.org/10.1111/pbaf.12154

Chen Q, Hua X, Jiang Y (2018) Contrarian strategy and herding behaviour in the Chinese stock market. Eur J Finance 24(16):1552–1568

Chin JY, Prevost AK, Gottesman AA (2002) Contrarian investing in a small capitalization market: evidence from New Zealand. Financial Rev 37(3):421–446

Chou PH, Wei KJ, Chung H (2007) Sources of contrarian profits in the Japanese stock market. J Empir Finance 14(3):261–286

Congressional Budget Office (2001) Uncertainty in social security's long-term finances: a stochastic analysis. https://www.cbo.gov/sites/default/files/107th-congress-2001-2002/reports/socsecuncertainty.pdf Accessed 30 Apr 2023

Cremer H, Pestieau P (2000) Reforming our pension system: is it a demographic, financial or political problem? Eur Econ Rev 44(4–6):974–983. https://doi.org/10.1016/S0014-2921(99)00054-9

De Bondt WFM, Thaler RH (1987) Further evidence on investor overreaction and stock market seasonality. J Finance 42(3):557–581

De Bondt WFM, Thaler R (1985) Does the stock market overreact? J Finance 40(3):793–805

De Haan L, Kakes J (2011) Momentum or contrarian investment strategies: evidence from Dutch institutional investors. J Bank Financ 35(9):2245–2251

Devolder P, Levantesi S, Menzietti M (2021) Automatic balance mechanisms for notional defined contribution pension systems guaranteeing social adequacy and financial sustainability: an application to the Italian pension system. Ann Oper Res 299(1–2):765–795. https://doi.org/10.1007/s10479-020-03819-x

Dichtl H, Drobetz W (2011) Portfolio insurance and prospect theory investors: popularity and optimal design of capital protected financial products. J Bank Financ 35(7):1683–1697

Dierkes M, Erner C, Zeisberger S (2010) Investment horizon and the attractiveness of investment strategies: a behavioral approach. J Bank Financ 34(5):1032–1046

Engle RF, Susmel R (1993) Common volatility in international equity markets. J Bus Econ Stat 11(2):167–176

Estep T, Kritzman M (1988) TIPP: insurance without complexity. J Portf Manag 14(4):38

Fujisawa Y, Li JSH (2012) The impact of the automatic balancing mechanism for the public pension in Japan on the extreme elderly. N Am Actuar J 16(2):207–239. https://doi.org/10.1080/10920277.2012.10590638

Giang TL, Pfau WD (2008) Demographic changes and the long-term pension finances in Vietnam: a stochastic actuarial assessment. J Popul Ageing 1(2–4):125–151. https://doi.org/10.1007/s12062-009-9010-8

Government Pension Investment Fund [GPIF] (2020a) About change of strategic asset allocation. https://www.gpif.go.jp/topics/Adoption%20of%20New%20Policy%20Portfolio_Jp_details.pdf [in Japanese]

GPIF (2020b) Description for investment principles. https://www.gpif.go.jp/en/about/Description_for_Investment_Principles_2020.pdf. Accessed 30 Apr 2023

GPIF (2022) Annual report fiscal year 2021, https://www.gpif.go.jp/en/performance/annual_report_fiscal_year_2021.pdf. Accessed 30 Apr 2023

Godínez-Olivares H, Boado-Penas MDC, Haberman S (2016) Optimal strategies for pay-as-you-go pension finance: a sustainability framework. Insur: Math Econ 69:117–126. https://doi.org/10.1016/j.insmatheco.2016.05.001

Herold U, Maurer R, Stamos M et al. (2007) Total return strategies for multi-asset portfolios. J Portf Manag 33(2):60

Hizu T (2020) Stochastic projection approach for adjusted benefit level of Japan's social security pension system. J Soc Secur Res 5(3):368–385. https://www.ipss.go.jp/syoushika/bunken/data/pdf/sh20120109.pdf

Justiniano A, Primiceri GE (2008) The time-varying volatility of macroeconomic fluctuations. Am Econ Rev 98(3):604–641

Kahneman D, Riepe MW (1998) Aspects of investor psychology. J Portf Manag 24(4):52–65

Kang J, Liu MH, Ni SX (2002) Contrarian and momentum strategies in the China stock market: 1993–2000. Pac Basin Finance J 10(3):243–265

Kitamura T, Nakashima K, Usuki M (2006) Risk analysis of pension reserve investment with macro economy indexation under the 2004 public pension reform. Econ Anal [in Japanese] 178:32–52. issued by Economic and Social Research Institute. Accessed 30 Apr 2023

Lakonishok J, Shleifer A, Vishny RW (1994) Contrarian investment, extrapolation, and risk. J Finance 49(5):1541–1578. https://doi.org/10.1111/j.1540-6261.1994.tb04772.x

Lee R, Tuljapurkar S (1998) Stochastic forecasts for social security. In: Wise DA (ed.). Frontiers in the economics of aging. University of Chicago Press, pp. 393–428

Leland H, Rubinstein M (1988) Comments on the market crash: six months after. J Econ Perspect 2(3):45–50

Mielczarek B (2013) Simulation model to forecast the consequences of changes introduced into the 2nd pillar of the Polish pension system. Econ Model 30:706–714. https://doi.org/10.1016/j.econmod.2012.09.053

Ministry of Finance (2023a) Breakdown of the outstanding amount of general bonds by remaining years to maturity. https://www.mof.go.jp/english/policy/jgbs/reference/Others/outstanding01.pdf. Accessed 30 Apr 2023

Ministry of Finance (2023b) Considering finances for the future of Japan. https://www.mof.go.jp/zaisei/current-situation/situation-comparison.html [in Japanese]. Accessed 30 Apr 2023

Ministry of Health, Labour and Welfare [MHLW] (2019a) Current state and outlook of finances related to national pension and welfare pension-financial verification results for 2019, R1. https://www.mhlw.go.jp/content/12601000/000540584.pdf [in Japanese]. Accessed 30 Apr 2023

MHLW (2019b) Summaries of the 2019 actuarial valuation and the financial implications of the reform options. https://www.mhlw.go.jp/content/2019_Actuarial_Valuation.pdf. Accessed 30 Apr 2023

MHLW (2019c) Annual actuarial report on the public pension system in Japan fiscal year 2019 (key points) https://www.mhlw.go.jp/english/org/policy/dl/p36-37a2019_fy_keypoints.pdf. Accessed 30 Apr 2023

MHLW (2020a) 2019 (R1) fiscal verification result report—Financial status and outlook for national pension and welfare pension (detailed version). https://www.mhlw.go.jp/content/12500000/2019report.pdf [in Japanese]. Accessed 30 Apr 2023

MHLW (2020b) Financial verification of public pension system in 2019 (peer review). https://www.mhlw.go.jp/stf/shingi2/0000112819_00001.html [in Japanese]. Accessed 30 Apr 2023

Mun JC, Vasconcellos GM, Kish R (1999) Tests of the contrarian investment strategy evidence from the French and German stock markets. Int Rev Financial Anal 8(3):215–234
Nakashima K, Kitamura T (2021) Effectiveness of public pension revisions considering economic fluctuations. J Soc Secur Res (Shyakai Hosyo Kenkyu) [in Japanese]. Accessed 30 Apr 2023
National Institute of Population and Social Security Research (2017) Population projections for Japan (2017): 2016 to 2065, appendix: Auxiliary. Projections, 2066–2115. https://fpcj.jp/wp/wp-content/uploads/2017/04/1db9de3ea4ade06c3023d3ba54dd980f.pdf. Accessed 30 Apr 2023
Organization for Economic Co-operation and Development (2021a) Pensions at a glance 2021, OECD and G20 indicators. https://www.oecd.org/publications/oecd-pensions-at-a-glance-19991363.htm
OECD (2021b) Annual survey of large pension funds and public pension reserve funds 2020. https://www.oecd.org/finance/survey-large-pension-funds.htm. Accessed 30 Apr 2023
Perold AF, Sharpe WF (1988) Dynamic strategies for asset allocation. Financial Anal J 44(1):16–27
Ramiah V, Cheng KY, Orriols J et al. (2011) Contrarian investment strategies work better for dually-traded stocks: Evidence from Hong Kong. Pac Basin Finance J 19(1):140–156
Rubinstein M, Leland HE (1981) Replicating options with positions in stock and cash. Financial Anal J 37:63–72
Sakamoto J (2005) Japan's pension reform. Social Policy Discussion. Paper 0541. Accessed 30 Apr 2023
Sakamoto J (2008) Roles of the social security pension schemes and the minimum benefit level under the automatic balancing mechanism. Nomura Res Pap 125. Accessed 30 Apr 2023
Schwert GW (2011) Stock volatility during the recent financial crisis. Eur Financial Manag 17(5):789–805
Schwert GW (1989) Why does stock market volatility change over time? J Finance 44:1115–1153
Sharpe WF (1987) Integrated asset allocation. Financ Anal J 43(5):25–32. https://doi.org/10.2469/faj.v43.n5.25
Shefrin H, Statman M (1993) Behavioral aspects of the design and marketing of financial products. Financ Manage 22:123–134
Usuki M, Kitamura T, Nakashima K (2003) Employee's pension finance and risk analysis—focusing on the discussion of fixed premium models, NLI-Research Institute Bulletin. https://www.nli-research.co.jp/files/topics/36203_ext_18_0.pdf [in Japanese]. Tokyo, 29, issued by NLI-Research Institute, pp. 1–56. Accessed 30 Apr 2023
Vidal-Meliá C, Boado-Penas MDC, Settergren O (2009) Automatic balance mechanisms in pay-as-you-go pension systems. Geneva Paper Risk Insur Issue Pract 34(2):287–317. https://doi.org/10.1057/gpp.2009.2
Wei KD, Wermers R, Yao T (2015) Uncommon value: the characteristics and investment performance of contrarian funds. Manag Sci 61(10):2394–2414

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