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Risk Sharing within Pension Schemes

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Abstract

The current redesign of the Dutch pension system includes the following elements: a dened contribution pension for each participant plus a *solidarity buffer* that serves as a risk-sharing mechanism to smooth returns between participants in the pension fund. In this paper we briefly summarize the literature on optimal risk sharing. We also assess the welfare effects of the current Dutch pension proposal and compare this to theoretically optimal risk sharing arrangements. We show that a solidarity buffer with sufciently risky investment can achieve results that approximate the optimal utility benets of "unconstrained" intergenerational risk sharing.

Samenvatting

Het huidige voorstel voor de herinrichting van het Nederlandse pensioenstelsel kent de volgende elementen: een premiepensioen voor elke deelnemer plus een *solidariteitsbuffer* die wordt gebruikt als risicodelingsmechanisme om het rendement tussen de deelnemers in het pensioenfonds te verdelen. In dit paper geven we een korte samenvatting van de literatuur over optimale risicodeling. We bekijken ook de welvaartseffecten van het huidige Nederlandse pensioenvoorstel en vergelijken dit met theoretisch optimale risicodelingsmechanismen. We laten zien dat een solidariteitsbuffer met een voldoende risicovolle investering resultaten kan opleveren die dicht in de buurt liggen van de optimale nutsvoordelen van "ongelimiteerde" intergenerationele risicodeling.

1 Introduction

Pension systems in many countries are being reformed in order to facilitate economic and demographic changes. Risk sharing within a pension fund is one of the desired characteristics of the new systems. One way to mitigate risk would be a mechanism to smooth fluctuations in investment returns between the participants in a pension fund, where surpluses are allocated to a buffer fund to spread fluctuations in investment returns over a range of calendar years and between pension generations. Proposals for a similar smoothing buffer are presently being debated in The Netherlands as part of the "new pension deal" (see, e.g. Metselaar et al., 2020)

In this paper, we briefly summarize the literature on optimal risk sharing. We also assess the welfare effects of the current Dutch pension proposal and compare this to theoretically optimal risk sharing arrangements. We show that a solidarity buffer with sufficiently risky investment can achieve results that approximate the utility benefits of optimal intergenerational risk sharing, but also succeeds in mitigating the downside risk of underfunding for the younger generation that is just entering the pension fund.

2 Theoretical Results on Risk Sharing

A pension fund offers the opportunity of sharing risks between the participants in the fund. Risks can be shared between participants of the same generation; this we will call *intra-generational risk sharing*. A pension fund also provides opportunities of sharing risks between different generations, including future generations that have not yet entered the fund. This latter form of risk sharing is known as *inter-generational risk sharing*.

Risk sharing theory can be traced back to Borch (1962) who studied the existence of equilibria in insurance and reinsurance markets in the 1960s. For an elaborate review of the theoretical aspects of risk sharing, we refer to Aase (2002). Whenever economic agents share risks collectively, it is nearly always possible to find a Pareto-improving solution that leaves all agents better off compared to the autarky (= non-sharing) solution. These results are very general and also hold when all agents have different utility functions and different capital distributions. The only thing required is that all agents have increasing and concave (= von Neuman–Morgenstern) utility functions and contribute with a net positive value to the risk-pool.

2.1 Intra-generational Risk Sharing

We begin by considering *intra*-generational risk sharing. We consider the stylized case where all participants enter the pension fund on the same date $t = 0$ and also all retire on the same date T. We consider N participants in the pension fund, where each participant $n = 1 \dots N$ has a different utility function $U_n()$. Each agent has a stochastic stream of pension contributions over the agent's working life from time $t = 0$ to time $t = T$. The present value of the stream of contributions at time $t = 0$ is denoted by $X_n(0)$. In an arbitrage-free market (such as the Black-Scholes market of Section 3), there exists a positive pricing kernel $M(T)$ for that financial market. The pricing kernel is capable of pricing all financial risks, such as interest rates, equity, inflation, etc. With the pricing kernel, we can calculate the present value $X_n(0)$ of the stream of pension contributions.

We now assume that participant n seeks to maximize at $t = 0$ the expected utility $\mathbb{E}\left[U_n\left(X_n(T)\right)\right]$ of pension capital $X_n(T)$ at the retirement date T. As stated earlier, the utility function $U_n()$ can be very general, including path-dependent and state-dependent utility functions. Due to the agent's access to the financial market, the agent can solve the following optimization problem: the agent chooses the pension capital at retirement which maximizes the expected utility: $\max_{X_n(T)} \mathbb{E}\left[U_n\left(X_n(T)\right)\right]$ subject to the budget constraint that the present value of pension capital $X_n(T)$ at retirement date T is equal to the present value of the pension contributions x_n. At this point, we note that the stochastic nature of the stream of contributions has little impact on the optimization problem: only the present value at $t = 0$ of the stream of contributions matters.

The optimal solution $X_n^*(T)$ for the pension capital at retirement date T for participant n can be represented as $X_n^*(T) = I_n(\kappa_n M(T))$, where $I_n()$ denotes the inverse of the marginal utility $U_n'()$ and κ_n is a scaling constant that ensures that the optimal capital satisfies the participant's budget constraint. The optimal solution of *each* participant is tied to the *same* pricing kernel $M(T)$. The pricing kernel is not just a mathematical object, it corresponds to a traded portfolio known as the *growth-optimal portfolio*.[1] Hence, participants use the return of the financial market to optimize their individual utility $U_n()$ and to match their budget $X_n(0)$. Consequently, the optimal pension capital of every participant correlates positively with the performance of the financial market. This is a general feature of optimal risk transfers: optimal risk sharing leads to positively correlated[2] capital distributions for all participants.

The structure of each participant's optimal capital highlights the following features of an optimal risk transfer (see, e.g. Aase, 2002):

- All participants pool their contribution streams and create a market with a pricing kernel $M(T)$.
- Each participant uses the same pricing kernel $M(T)$ as an index to create a capital distribution that optimizes the participant's individual capital. This leads to positively correlated (i.e. co-monotone) capital distributions for all participants.
- The collective behaviour of all participants can be modelled by a "representative agent" whose utility function is the weighted average of all individual utility functions. The pricing kernel $M(T)$ is equal to the marginal utility of the representative agent.

In our case, we already have a pre-existing financial market with a given pricing kernel $M(T)$. This pre-existing financial market allows participants to follow an investment strategy that maximizes their utility. The optimal pension capital distribution of each individual participant is linked to the *same* pricing kernel $M(T)$. Hence, due to the existence of a financial market, pooling the financial risks of all participants within the same generation leads to *no extra utility gain*, as all participants are exposed to the same financial market risks and as no additional diversification benefits can be obtained by pooling the financial risks of the participants.

This negative result is somewhat extreme, as we only consider traded financial risks. For non-traded financial risks, such as individual career paths, wage inflation or mortality

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[1] The exact correspondence between $M(T)$ and the growth-optimal portfolio $\tilde{X}(T)$ is given by $1/M(T) \equiv \tilde{X}(T)$ since the growth-optimal portfolio maximizes the expected utility of a log-utility investor with utility $U(X) = \ln(X)$ and $U'(X) = 1/X = M$.

[2] The technical term is: *co-monotone* capital distributions.

risk, there is definitely an advantage in pooling and diversifying those risks among participants. On top of that, the pension fund acts as a facilitator as it grants each participant much more efficient access to the financial market. Furthermore, the pension fund acts as a “disciplining agent” by ensuring that each participant remains committed to an investment plan that stretches out over multiple decades.

2.2 Inter-generational Risk Sharing

Thus far, we have assumed that all participants in the pension fund have the same horizon $[0, T]$. We now turn to the case where we have multiple overlapping generations that participate in the same pension fund.

Let us consider two generations which are spaced L years apart. As such, the first generation has a working career from 0 to T and the second generation from L to $T + L$. We will represent the utility function of each generation (or of its representative agent) as $U_0()$ and $U_L()$. In the stand-alone situation, the first generation uses the return $M(T)/M(0)$ on the pricing kernel over $[0, T]$ to optimize its pension capital $X_0^*(T)$, while the second generation uses the return $M(T + L)/M(L)$ to optimize its pension capital $X_L^*(T + L)$ during the interval $[L, T + L]$. Thus, in the stand-alone situation both generations use the market-return over a horizon of T years for their pension capital, but both generations now use a *different* pricing kernel.

What happens when we pool the pension contributions of both generations into a single pension fund? By pooling both generations, we create a representative agent (or a social planner) with a longer investment horizon of $T + L$ years. The expected return on the financial market over $T + L$ years is higher than the expected return over T years. By allocating the expected extra return to both generations, they can both achieve a better expected utility relative to the autarky solution. This means that intergenerational risk sharing leads to a strict welfare improvement for both generations compared to the stand-alone situation. This result has been noted by many authors, e.g. Teulings and de Vries (2006), Gollier (2008), Cui et al. (2011), and Werker (2017). The pension fund can now act as a social planner for both generations, allowing the second generation participants to “pre-invest” their future pension contributions L years before they enter the pension fund. It is important to note that the pension entitlements of both generations are explicitly defined.

Let us consider some pitfalls of intergenerational risk sharing. As noted by Gollier (2008) and Werker (2017), the improvement in expected utility for both generations comes at a price. The probability distribution of the pension capital becomes *more risky* for both generations; this implies that the probability of bad (or good) outcomes increases. Even though the *expected* utility increases for both generations, this does not mean that both generations always obtain a better pension result in every state of the world.

An important way that this problem manifests itself is as follows. The pension fund begins at time $t = 0$ by investing the present value $x_0 + x_L$ of the contributions of both generations. Relative to the present value x_0 of the contributions of the first generation this creates a leveraged position, which is financed by borrowing the amount x_L. After L years, this loan can be paid off by the contributions from the new generation entering the pension fund at time $t = L$.

At time $t = 0$, this is an arrangement that improves the expected utility for both generations. At time $t = L$, the situation can be different. The participants belonging to the new generation entering the pension fund at time L have more information available than at $t = 0$: they can observe the realized investment return made by the pension fund. If the returns have been poor during the first L years, then the market value of the assets of the pension fund will have decreased in value.

The pension entitlements $X_0^*(T)$ and $X_L^*(T+L)$ of both generations are explicitly defined and represent the Pareto-optimal risk sharing agreement that was arranged at time $t = 0$. Consequently, at time L, new generation participants can compute their "net pension value" as the difference in present value (at time $t = L$) between their pension entitlements $X_L^*(T+L)$ and the stream of their pension contributions. At this point we wish to remind the reader that the random variable $X_L^*(T+L)$ has a positive correlation with the performance of the financial market. This means that when markets have performed poorly in the first L years, the market value at time L of $X_L^*(T+L)$ has likewise decreased in value. This effect was also noted by Teulings and de Vries (2006).

What happens when the net pension value is negative for the new generation? In that case, the new generation is getting a "bad deal": the present value of its pension entitlements is worth less than the present value of its pension contributions. In such case, the new generation could decide not to enter the pension fund and instead to opt for the autarky solution where the new generation can always generate a pension capital that is budget neutral. If the new generation exercises this "entry option" it saves its own skin, but this means that the first generation will be left behind in an underfunded pension fund. Thus, when the new generation has an entry option at time $t = L$, then the first generation realizes that it is exposed to this shortfall risk and will also choose the autarky solution at $t = 0$. The autarky solution for both generations corresponds to a *defined contribution* pension system (without any additional risk sharing), where the market value of the optimal pension capital for each generation equals the market value of its pension contributions.

How can we avoid the prisoner's dilemma that leads to the autarky solution? One possible solution is to enforce participation in the pension fund by each generation. This is the solution proposed by, among others, Cui et al. (2011). While this is, theoretically, a feasible solution to reap the benefits of intergenerational risk sharing, it does not address the problem of later generation noticing that they are getting a “bad deal” when entering the pension fund after an economic down-turn. The pension crisis that we are currently witnessing was created by exactly this phenomenon: two decades of unfavourable financial market developments have created an underfunded pension system which has led to tensions between the older and younger generations in the Dutch pension system.

Are there other ways to resolve this problem? If we keep the net pension value for the second generation positive for all states of the world, then the second generation is guaranteed to be better off. But this means that the first generation is guaranteed to be worse off than in the autarky solution; so this can never lead to a Pareto-optimal solution. We could ensure that the net pension value for the second generation is exactly zero for all states of the world. But then we re-create the autarky solution for the second generation, meaning that there is never a capital transfer (positive or negative) between the generations at $t = L$ and the first generation then also reverts to the autarky solution.

If we want to maintain some form of intergenerational risk sharing then we must allow for some transfer of capital (positive and negative) between generations. However, we must also ensure that in any state of the world the total transfer of value is not too large. This sets limits to how valuable the “entry option” can be for any new generation that enters the pension system and makes it mandatory participation for all generations more sustainable. We will consider two possible approaches to this problem:

- Pre-invest the full present value of the contributions by the second generation, but impose a “return guarantee” such that the pension value of the second generation is at least 90% of its pension contributions when entering the pension fund at time $t = L$.
- Pre-invest only a limited amount, say 10%, of the present value of the contributions by the second generation. This ensures that the second generation will always have a pension value of at least 90% of its pension contributions when entering the pension fund at time $t = L$. This is a stylized version of the current Dutch pension proposal where 10% of each pension contribution is invested in a “solidarity buffer”.

In the next section, we work out these ideas in more detail for a Black-Scholes economy with CRRA utilities.

3 Black-Scholes Economy with CRRA Utility

The financial market model has a single risk factor which we refer to as “stock market risk”. Exposure to this risk factor induces risk and an expected return that need to be balanced. We will work with monetary quantities that are already expressed in discounted terms, hence our model will be similar to a model where the risk-free interest rate is equal to 0.

As discussed in the introduction, pension fund participants are exposed to risk and return before they actually enter the fund. To analyse their optimal trade-off between risk and return, it does not make much difference whether it involves stock market risk or interest rate risk. In practical situations a fund can simply look at the overall risk/return trade-off of its total portfolio. We also exclude longevity risk and non-traded inflation risk, since these are generally considered to be much smaller than investment risk. Let us define the parameters of interest:

- a systematic risk factor process $W(t)$ with (constant) market-price of risk λ;
- stock, with exposure to W_t, that has (constant) volatility σ;
- we assume that pension participants want to maximize the expected utility of their pension capital at retirement using a power-utility function (CRRA utility) with constant risk aversion parameter γ;
- the working career of each pension participant is T years.

If we denote the (discounted) stock price at time t by $S(t)$, it evolves according to the stochastic process

$$dS(t) = \lambda\sigma S(t)\,dt + \sigma S(t)\,dW(t). \tag{3.1}$$

If we set the initial stock price at time 0 to $S(0) = 1$, then for each time $t > 0$ the stock price is a log-normal random variable

$$S(t) = \exp\left\{(\lambda\sigma - \tfrac{1}{2}\sigma^2)t + \sigma W(t)\right\}. \tag{3.2}$$

The per-annum expected (geometric) excess return on the stock is $\mathbb{E}[\ln S(t)/t] = (\lambda\sigma - \frac{1}{2}\sigma^2)$. The pricing kernel in this economy is given by the stochastic process

$$dM(t) = -\lambda M(t)\,dW(t). \tag{3.3}$$

The pricing kernel defines the “risk-neutral” probability measure $\mathbb{Q}$, where the (discounted) prices of all traded assets become martingales. Under this new probability measure $\mathbb{Q}$, the original Brownian Motion $W(t)$ is transformed into a Brownian Motion with a negative drift $W(t) \mapsto W^{\mathbb{Q}}(t) - \lambda t$. For example, the stock price process under the measure $\mathbb{Q}$ follows

$$dS(t) = \lambda\sigma S(t)\,dt + \sigma S(t)\left(dW^{\mathbb{Q}}(t) - \lambda\,dt\right) = \sigma S(t)\,dW^{\mathbb{Q}}(t) \tag{3.4}$$

which is indeed a martingale.

The representative agent for each pension generation has a constant relative risk aversion $\gamma > 0$ with a power-utility function of the form[3]:

$$U(x) = \frac{x^{(1-\gamma)}}{1-\gamma} \qquad U'(x) = x^{-\gamma} \qquad I(y) = y^{-1/\gamma} \tag{3.5}$$

where we also show the marginal utility $U'(x)$ and the inverse function $I(y)$ of the marginal utility.

3.1 Autarky Solution

If we consider all pension generations in isolation, they can optimize the expected utility of their pension capital $X(T)$ at retirement as

$$\begin{aligned} &\max_{X(T)} \mathbb{E}\left[U\left(X(T)\right)\right] \\ &\text{s.t. } \mathbb{E}\left[M(T)X(T)\right] = \mathbb{E}^{\mathbb{Q}}\left[X(T)\right] = x \end{aligned} \tag{3.6}$$

where the second line expresses the budget constraint that the present value at time $t = 0$ of the pension capital $X(T)$ must be equal to the present value of the pension contributions, which we denote by x.

The optimal pension capital has the form $X^*(T) = I\left(\kappa M(T)\right)$, where κ is a scaling constant that must be set such that the budget constraint is solved. After solving for κ, we obtain an explicit representation for the optimal pension capital

$$X^*(T) = x \exp\left\{\tfrac{(2\gamma-1)\lambda^2}{2\gamma^2} T + \tfrac{\lambda}{\gamma} W(T)\right\} \tag{3.7}$$

The optimal expected utility that the agent can obtain is

$$\mathbb{E}\left[U\left(X^*(T)\right)\right] = \frac{\left(x e^{\frac{\lambda^2}{2\gamma} T}\right)^{1-\gamma}}{1-\gamma} \tag{3.8}$$

where the expression in parentheses $xe^{\lambda^2/(2\gamma)T}$ denotes the *certainty equivalent* of the expected utility. The certainty equivalent amounts to receiving a certain return (above the risk-free rate) of $\lambda^2/(2\gamma)$ for a period of T years on the present value of x of the pension contributions.

3.2 Optimal Risk Sharing

We now analyse the optimal risk sharing between two pension generations spaced L years apart. In this analysis, we assume that each generation has mandatory participa-

[3]The limiting case for $\gamma = 1$ is $U(x) = \ln x$.

tion in the pension fund and cannot exercise the "entry option". We will denote the optimal pension capital (after risk sharing) of the first generation by $X_0^\dagger(T)$ and of the second generation by $X_L^\dagger(T+L)$.

We can determine the optimal solution for both generations by maximizing the utility of a social planner with utility function $\alpha U(X_0) + U(X_L)$ where the parameter $\alpha > 0$ is a tuning parameter that balances the interests of both generations. Any choice[4] for α that leads to an expected utility improvement for both generations (compared to the autarky solution) is a Pareto-optimal solution. The optimization problem for the social planner (i.e. the pension fund) can be formulated as

$$\max_{X_0(T), X_L(T+L)} \mathbb{E}\left[\alpha U\big(X_0(T)\big) + U\big(X_L(T+L)\big)\right] \quad (3.9)$$
$$\text{s.t. } \mathbb{E}\left[M(T)X_0(T) + M(T+L)X_L(T+L)\right] = 2x$$

where we assume that the present value of the pension contributions (as seen at $t = 0$) for both generations is equal to x. Hence, the total budget available for the social planner is $2x$. In the formulation above, the pension fund (i.e. the social planner) decides at time $t = 0$ on the optimal allocation of pension capital $X_0(T)$ at retirement date T for the first generation and the optimal capital $X_L(T+L)$ at retirement date $T+L$ for the second generation subject to a budget constraint that represents the present value of pension wealth and pension contributions at $t = 0$.

The optimal pension capital for both generations can be characterized as

$$X_0^\dagger(T) = I\big(\alpha\kappa M(T)\big) \qquad X_L^\dagger(T+L) = I\big(\kappa M(T+L)\big). \quad (3.10)$$

We still have one parameter κ to solve the budget constraint for the social planner, where the tuning parameter α determines how the capital is allocated to the two generations. On the other hand, we can also observe that the optimal capital of both generations has exactly the same functional form as the autarky solution, except for the parameters $\alpha\kappa$ and κ. However, the only role of these parameters is to match the budget constraint. Because there is a monotonically decreasing[5] correspondence between $(\alpha)\kappa$ and the market value at $t = 0$ of the optimal capital, we can represent the optimal allocation of the total capital to each generation as an autarky solution with adjusted initial budgets $\left(x + \pi\right)$

[4] This does not mean that we can choose α freely. Instead, it has to be "fine-tuned" such that we obtain a Pareto-optimal solution. In fact, α is bounded between two positive values where at each bound the expected utility of one generation is equal to the autarky solution (and the other generation is better off) and vice versa. As the autarky solutions are a feasible solution for (3.9), we know that these bounds on α must exist. Each value for α between these two bounds leads to a utility-improving solution for both generations.

[5] This is true because the (inverse) marginal utility is a monotonically decreasing function.

and $(x-\pi)$:

$$
\begin{aligned}
X_0^{\dagger}(T) &= (x+\pi)\, e^{\frac{(2\gamma-1)\lambda^2}{2\gamma^2}T+\frac{\lambda}{\gamma}W(T)} \\
X_L^{\dagger}(T+L) &= (x-\pi)\, e^{\frac{(2\gamma-1)\lambda^2}{2\gamma^2}(T+L)+\frac{\lambda}{\gamma}W(T+L)}.
\end{aligned}
\tag{3.11}
$$

The pension fund (i.e. the social planner) allows the second generation to extend its investment horizon by L extra years. This leads to larger expected returns for the second generation. By making an up-front payment of π to the first generation, both generations can now benefit from the extra return that is generated and improve their expected utility. The certainty equivalent of the expected utility at $t = 0$ for both generations can be expressed as

$$
\begin{aligned}
\overline{X_0^{\dagger}} &= (x+\pi)\, e^{\frac{\lambda^2}{2\gamma}T} \\
\overline{X_L^{\dagger}} &= (x-\pi)\, e^{\frac{\lambda^2}{2\gamma}(T+L)}.
\end{aligned}
\tag{3.12}
$$

If we choose[6] $\pi \approx \frac{1}{2}x\lambda^2/(2\gamma)L$, then both generations equally divide the extra utility value $x\lambda^2/(2\gamma)L$ and both enjoy both a strict increase in expected utility. As seen from time $t = 0$, both generations are better off in expected utility terms by pooling and optimally sharing their resources. Note, that the first generation's investment policy is unchanged from the autarky solution, except that it can now invest a larger amount: $(x+\pi)$ instead of x. Hence, the gains from optimal risk sharing are achieved without increasing the riskiness of the investment returns of the first generation. On the other hand, the first generation is exposed to the risk of the second generation choosing not to enter the pension fund at time $t = L$.

What happens at time $t = L$, when the second generation enters the pension fund? Starting from time 0, the pension fund has "pre-invested" the amount $x-\pi$ and has followed the optimal investment strategy to replicate the optimal pay-off $X_L^{\dagger}(T+L)$ for the second generation. This risky pre-investment strategy for the first L years is exactly what generates the extra expected utility value, whereas the autarky solution would be equivalent to following a risk-free pre-investment strategy for L years. The value at time L of the second generation's assets is $X_L^{\dagger}(L) = (x-\pi)\exp\{\frac{(2\gamma-1)\lambda^2}{2\gamma^2}L + \frac{\lambda}{\gamma}W(L)\}$. This is a random variable that depends on the development of the risk factor process $W(L)$ from time 0 to time L. When the financial market has performed poorly, then $W(L)$ will be negative. For values of $W(L)$ below (approximately) $-\frac{1}{2}(\frac{3}{2}\gamma - 1)\lambda L$, the value $X_L^{\dagger}(L)$ is below the present value x of the pension contributions of the second generation. The expected utility will then

[6] This is an approximate expression, based on a first order Taylor expansion in $\lambda = 0$. For the remainder of this paper, we continue to use Taylor approximations whenever this leads to more concise expressions.

be smaller than the autarky value, which is based on investing an amount x for T years. On the other hand, for positive values of $W(L)$ the second generation enters the pension fund with a larger capital position (and larger utility) than the autarky value.

3.3 Bounded Risk Sharing

As discussed previously, the poor performance of financial markets can create tensions between the old and young generations, as the present value of the pension entitlements can be much less than the market value of the contributions of the young generation. We therefore want to analyse the utility benefits of a pension with "bounded" risk sharing between the generations. The constraint we will consider is that the present value at time $t = L$ of the pension entitlements $X_L(L)$ never falls below the lower bound βx at time L, where we take $0 < \beta < 1$.

To analyse this problem, we will first formulate the unconstrained optimization problem (3.9) in a different form. In the original formulation, the pension fund (or the social planner) decides at time $t = 0$ the optimal allocation of the pension capital $X_0(T)$ and $X_L(T + L)$ for both generations. We can also formulate the problem with a different perspective, where the pension fund only invests on behalf of both generations from $t = 0$ until $t = L$. At time L the assets of the pension fund are divided over both generations and after time L both generations continue independently and invest optimally according to their own utility function (as in autarky). From equation (3.8), we can infer that the expected utility at time $t = L$ of starting with an initial amount $X(L)$ at time L and investing optimally for another S years is given by $U_S\big(X(L)\big) := \big(X(L)e^{\lambda^2/(2\gamma)S}\big)^{(1-\gamma)}/(1-\gamma)$. Note that this expression is identical to a standard power-utility function, except that we multiply the utility by a constant factor $e^{\lambda^2(1-\gamma)/(2\gamma)S}$ which represents the utility gain of investing optimally for S additional years.

Using the modified utility functions $U_{T-L}()$ and $U_T()$, we can formulate the constrained risk sharing problem as

$$\begin{aligned} \max_{X_0(L),X_L(L)} \; & \mathbb{E}\big[\alpha U_{T-L}\big(X_0(L)\big) + U_T\big(X_L(L)\big)\big] \\ \text{s.t. } & \mathbb{E}\big[M(L)\big(X_0(L) + X_L(L)\big)\big] = 2x \\ & X_L(L) \geq \beta x \end{aligned} \tag{3.13}$$

At time L, the first generation has $T - L$ years left until retirement, hence its utility is represented by $U_{T-L}\big(X_0(L)\big)$. In the formulation above, the pension fund (i.e. the social planner) decides on the optimal division at time L of the pension fund's assets into $X_0(L)$ for the first generation and $X_L(L)$ for the second generation subject to a budget constraint that represents the present value of the pension contributions at $t = 0$. Furthermore, we have the inequality constraint that the pension assets $X_L(L)$ of the second generation never fall below a fraction β of the present value x at time L of the second generation's pension contributions.

At this point we note that the difference between the utility functions $U_S(X)$ and $U(X)$ is only a constant scaling factor. The fact that we multiply both utilities by a different constant scaling factor does not affect the structure of the optimal solution of (3.13) since we can fold any utility scaling factor into the tuning parameter α. The optimal allocation of pension assets $X_L^{\S}(L)$ to the first generation can still be represented as an autarky solution with adjusted initial budget ax. Due to the inequality constraint, the optimal allocation to the second generation is a "floored" autarky solution:

$$\begin{aligned} X_0^{\S}(L) &= ax\, e^{\frac{(2\gamma-1)\lambda^2}{2\gamma^2}L+\frac{\lambda}{\gamma}W(L)} \\ X_L^{\S}(L) &= \max\left\{ bx\, e^{\frac{(2\gamma-1)\lambda^2}{2\gamma^2}L+\frac{\lambda}{\gamma}W(L)}\ ,\ \beta x \right\}. \end{aligned} \tag{3.14}$$

In this representation of the optimal asset allocation, we still have to determine the scaling parameters $a, b > 0$ such that we satisfy the budget constraint $\mathbb{E}\left[M(L)\left(X_0^{\S}(L) + X_L^{\S}(L)\right)\right] = 2x$ and that we find a welfare improving solution for both generations, compared to the autarky solution.

We see that the optimal solution for constrained risk sharing is such that the pension fund pre-invests the pension contributions from the second generation from time 0 to L and that the pension fund includes a *return guarantee* to ensure that the pension assets of the new generation do not fall below the bound βx. However, limiting the downside risk in the investment strategy also means that there is less upside potential in the good states of the world. This implies that the total utility benefit for both generations will be less than the unconstrained risk sharing value $x\lambda^2/(2\gamma)L$.

3.4 Limited Pre-Investment

The optimal solution that we considered in the previous subsection boils down to replicating a return guarantee. For large pension funds, this would involve executing large-scale trades, which can be difficult (or disruptive) to achieve in financial markets. To address the problem of large-scale trading, we analyse in this subsection the utility benefits of pre-investing only a limited amount for the second generation. We consider a stylized version of the current Dutch pension proposal where only 10% of the present value x of the pension contributions is pre-invested for the second generation. This ensures that the second generation always has a pension value of at least 90% of the pension contributions when entering the pension fund at time $t = L$.

The problem formulation now slightly differs from Section 3.3, as the pension fund splits the assets for the second generation into two parts: $X_P(L) + \beta x$, where $X_P(L)$ represents the assets that are pre-invested at time $t = 0$. The pension fund chooses a "fix-mix" investment strategy, where it invests a constant portion δ of the pre-invested pension assets in stocks (and the remainder in risk-free investments). We denote the pre-invested amount at $t = 0$ by x_P, where x_P can differ from $(1 - \beta)x$, to allow for a value transfer between the two generations (similar to $(x - \pi)$ that we considered earlier). The probability distribution at time $t = L$ of the pre-invested assets $X_P(L)$ is given by

$$X_P(L;\delta) = x_P e^{\left(\delta\sigma\lambda - \frac{1}{2}(\delta\sigma)^2\right)L + \delta\sigma W(L)} \tag{3.15}$$

where we include δ as an argument to emphasize the dependence of the probability distribution of $X_P(L)$ on investment strategy δ.
We can now formulate the risk sharing problem as

$$\max_{X_0(L), x_P, \delta} \mathbb{E}\left[\alpha U_{T-L}\big(X_0(L)\big) + U_T\big(X_P(L;\delta) + \beta x\big)\right] \tag{3.16}$$
$$\text{s.t. } \mathbb{E}\left[M(L)X_0(L)\right] + x_P = (2 - \beta)x$$

where the budget constraint $(2 - \beta)x$ represents (at $t = 0$) the present value x of the first generation's pension contributions plus the present value $(1 - \beta)x$ of the second generation's pension contributions. The control variables for this optimization problem are the pension assets $X_0(L)$ allocated to the first generation at time L, and the scalars x_P and δ.
Using similar arguments as before, the optimal pension asset allocation for the first generation is a re-scaled autarky solution, as given in (3.14). The optimal solution can thus be obtained by finding three scalars (a, x_P and δ), such that the budget constraint is satisfied and that we find a welfare improving solution for both generations, compared to the autarky solution.

3.5 Numerical Illustration

We now illustrate our results with some numerical examples. For our calculations, we use the same parameter settings[7] as Werker (2017):

- market price of risk: $\lambda = 0.20$;
- stock price volatility $\sigma = 0.20$;
- risk aversion parameter $\gamma = 5$;
- market-value of pension contributions $x = 1$;
- working career $T = 40$ years;
- generation gap $L = 10$ years.

The qualitative results that we present here are robust for changes in the model setup, as evidenced by the explicit theoretical results that we derived in the previous section.

[7] Since we present all of our results in discounted terms, the risk-free interest rate plays no role in our results.

	$\overline{X_0}$	$X_0^{\mathbb{Q}}$	$\overline{X_L}$	$X_L^{\mathbb{Q}}$	$\mathbb{P}[X_L < 1]$	$\mathbb{P}[X_L < 0.9]$
Autarky	1.174	1.000	1.174	1.000	0.00	0.00
10% Pre-inv	1.189	1.014	1.189	0.986	0.47	0.00
90% Floor	1.193	1.018	1.193	0.982	0.41	0.00
Full IGR	1.196	1.020	1.196	0.980	0.35	0.11

Table 1: Utility Effects of Intergenerational Risk Sharing

The exact numerical outcomes we present in this illustration obviously depend on specific model and parameter assumptions.

In Table 1, we present the results of the model for various forms of risk sharing. The second column in the table shows the certainty equivalent value ($\overline{X_0}$) and the present value ($X_0^{\mathbb{Q}}$) at time $t = 0$ of the optimal pension capital entitlement for the first generation. The third column shows both numbers (at $t = 0$) for the second generation, where we report the present value $X_L^{\mathbb{Q}} = \mathbb{E}^{\mathbb{Q}}[X_L(L)] = \mathbb{E}[M(L)X_L(L)] = \mathbb{E}[M(T+L)X_L(T+L)]$. The right-hand column shows the probabilities $\mathbb{P}[X_L(L) < 1]$ and $\mathbb{P}[X_L(L) < 0.9]$ that the value $X_L(L)$ of the pension assets at time $t = L$ of the second generation is less than $x = 1$ or less than $0.9x$.

The top row in the table shows the results of the autarky solution. The certainty equivalent value of the optimal utility is for both generations equal to $e^{\lambda^2/(2\gamma)T} = e^{0.0040*40} = 1.174$. The present value at time $t = 0$ of the pension entitlements for both generations exactly equals the value of the pension contributions: $X^{\mathbb{Q}} = x = 1$. The probability of "under-funding" for the second generation is (by construction) equal to 0.

The bottom row in the table shows the results for unconstrained risk sharing. The certainty equivalent of the utility of investing an additional L years for both generations is $e^{\lambda^2/(2\gamma)L} = e^{0.0040*10} = 1.041$. Half of the excess value is donated by the second generation to the first generation, leading to a present value $X_0^{\mathbb{Q}} = 1.020$ for the first generation and $X_L^{\mathbb{Q}} = 0.980$ for the second generation. Even though the second generation starts with less initial value (0.980), it still has a utility gain, since it enjoys the benefits of L extra years of investment returns. The certainty equivalent value for both generations is equal to $\overline{X} = 1.196$ and is strictly larger than the autarky value for both generations. The improvement over the autarky value is an additional factor $1.196/1.174 = 1.019$, which is approximately half of the theoretical IGR-gain of 4.1%. The probability of under-funding for the second generation is 0.35. This means that after L years, the young generation has a chance of 1 out of 3 of receiving pension entitlements with a present value that is less than the present value of its pension contributions. Furthermore, the probability $\mathbb{P}[X_L(L) < 0.9]$ of receiving pension entitlements that are below 90% of the present value of the contributions is 0.11, thus a chance of 1 out of 9. The probability of receiving pension entitlements that are below 75% of the value of the contributions is less than 0.01

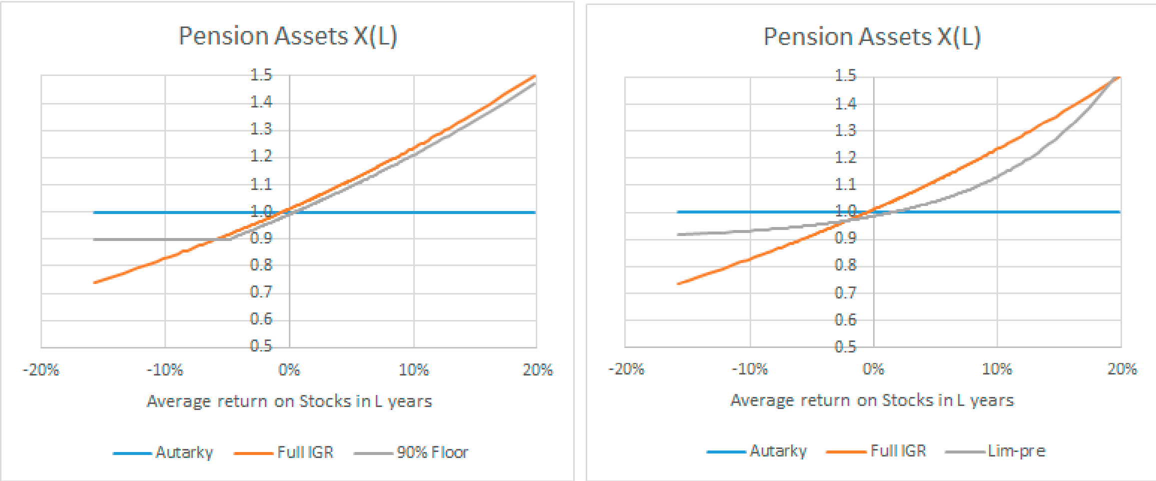

Figure 1: Distribution of pension assets for the second generation $X_L(L)$ at time L.

(this number is not reported in the table).

Let us now consider the effect of bounded risk sharing with a floor of $0.9x$, shown in the third row of the table. In such case, the pension fund guarantees that the new generation entering at time L gets pension assets $X_L(L)$ with a present value of at least 90% of its contributions. It is interesting to note that, for risk sharing purposes, this setup has only a small impact on the expected utility for both generations: the certainty equivalent is $\overline{X} = 1.193$ which is nearly equal to the unbounded value of 1.196. The gain over the autarky value is a factor of $1.193/1.174 = 1.016$ in this case. Even though we thereby impose an additional constraint on the optimization, the 90% floor is only binding in states of the world with low returns which are relatively unlikely to occur. Hence, the 90% floor only forces the outcome way from the unconstrained optimum in the tail of the distribution and has therefore relatively little impact on the overall outcome. By construction, the probability $\mathbb{P}[X_L(L) < 0.9]$ is now equal to zero. However, the probability $\mathbb{P}[X_L(L) < 1] = 0.41$ has slightly increased. This increase can be explained by the fact that the probability distribution of $X_L(L)$ is more concentrated around the average value of 0.982. Since this average value is below 1, the probability of under-funding increases. The optimal distribution of the pension assets with a 90% floor is illustrated in the left panel of Figure 1. Here we show the value of the pension assets of the second generation $X_L(L)$ at time L as a function of the average return $(1/L)\ln S(L)$ of the stock-market during the first L years. The orange line shows the distribution of pension assets for unconstrained risk sharing. The expected return on the stock market is $\mathbb{E}[\ln S(L)/L] = (\lambda\sigma - \frac{1}{2}\sigma^2) = 2\%$. The orange line drops below the value of 1 at an average stock market return of 0%, which occurs with a probability of 0.35 in our model. The orange line drops below a value of 0.9 at an average stock-market return of -6%, which happens with a probability of 0.11. The grey line in the left panel shows the pension assets for the floored risk sharing. We see clearly that the grey line remains constant at 0.90 for stock-market returns that are -5% or lower. This happens with a probability of 0.15. We can interpret the grey line also as the result of buying a protective put on the second generation's pension assets to ensure that the asset value for the second generation never drops below 0.90. The "concentration" of the value distribution of the pension assets is made visible here as the grey line is below the orange line for stock-market returns above -5%. This is the effect of the budget constraint: a better pay-off in bad states of the world must be compensated by a slightly lower pay-off in the other states of the world.

We now consider the case of risk sharing via a pre-investment limited to 10% of the future pension contributions of the second generation. This is shown in the second line of Table 1. When a limited amount is pre-invested, then the optimal solution is to take much more investment risk on the pre-investment in order to maximize the expected return on the pre-investment. The results we report in the table are for δ = 100%, i.e. 100% pre-investment in stocks. Again we note that this setup for the risk sharing has only a small impact on the expected utility for both generations: the certainty equivalent is $\overline{X}$ = 1.189 which is nearly equal to the unbounded value of 1.196. By definition, the probability $\mathbb{P}[X_L(L) < 0.9] = 0$ and the probability $\mathbb{P}[X_L(L) < 1] = 0.47$.

The optimal distribution of the pension assets of the second generation with 10% pre-investment is illustrated in the right-hand panel of Figure 1. The grey line in this panel shows the pension assets at time $t = L$ for the 10% pre-investment. We clearly see that the grey line remains above the level 0.90. The probability distribution of the assets is in fact a shifted log-normal distribution, with a lower bound at 0.90. This is the result of investing 0.90 in risk-free assets at $t = 0$ and holding 0.10 in stocks for L years. When we compare the grey lines in both figures, see that they are quite similar in shape. This is a visual clue to why the expected utility levels are quite similar for both types of risk sharing. The expected utility in the left panel is slightly higher, but it corresponds to replicating a put-option, which is a more complex investment strategy (with more transaction costs) than the simple buy-and-hold strategy shown in the right-hand panel.

4 Conclusions

In this paper we have briefly summarized the literature on optimal risk sharing. We have also assessed the welfare effects of the current Dutch pension proposal and have compared this to theoretically optimal risk sharing arrangements. A drawback of the optimal intergenerational risk sharing scheme is the possibility of significant under-funding of the pension scheme at the start of the working life of the young generation. However, we show that a solidarity buffer with a sufficiently risky investment policy can achieve results that are close to the utility benefits of optimal intergenerational risk sharing, but that it also mitigates the downside risk of under-funding for the young generation. Importantly, we show that these utility gains can be achieved without increasing the risk level of the pension returns for the generation closest to retirement.

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