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Financing an Uncertain Retirement Part II: Portfolio Construction

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Executive Summary

- The risk of having insufficient savings or even running out of money in retirement is not accounted for in typical economic models even though it cannot be hedged in financial markets and may affect retirees' consumption and investment behavior.
- In this paper, we augment the traditional retirement model to account for unknown required future expenses that reflect actual retiree spending and investment behavior more closely.
- Our model predicts that retiree spending will exhibit some volatility as individuals seek to preserve their wealth and their optimal asset allocation should slowly de-risk over time.
- Instead, when future consumption is unknown and has increasing uncertainty over time, rolling shorter-term investment strategies, such as a bond ladder, may be more suited to a retiree's needs.

Introduction

This paper is the second in a two-part series that explores the implications of uncertain future liabilities for savings and investment in retirement. The first paper, "Financing an Uncertain Retirement Part I: Spending Strategies," extends canonical retirement models to include uncertain required future expenses, such as out-of-pocket healthcare spending. The resulting model is a straightforward application of the common fact that people do not know how much money they will need in retirement and fear that they might run out of assets. Uncertain future expenses lead to behaviors that help address several otherwise-puzzling data among retirees, including slow wealth decumulation rates, low annuitization rates and volatile consumption in retirement.

Required but uncertain future expenses have material asset allocation implications as well. Even when the expense uncertainty cannot be easily hedged in the financial markets, its presence has investment implications. This paper makes three contributions to the literature on retirement savings: First, it presents and solves a model with uncertain future spending needs whose predictions more closely reflect real-world consumption and asset allocation behavior; second, it characterizes the subtle and nonmonotonic relationships among wealth, spending and asset allocation in the presence of unknown future expenses; and, finally, it describes potential ways to design investment portfolios and rebalancing strategies to account for uncertain future spending needs.

REQUIRED EXPENSES: MOTIVATION AND PARAMETERIZATION

A full 49% of American adults cite running out of money as their top retirement concern.[1] Unfortunately, common economic models do not accommodate this fear. In most economic models, a rational retiree would simply spend less as their wealth fell. That is, these models view all spending as a choice rather than a requirement. Instead, we propose to explicitly incorporate these concerns, as individuals face unknown required future expenses at unknown times throughout their retirement. There are many potential sources of these shocks: unexpected home repairs or maintenance, potential tax/policy changes or even uncertainty over future preferences. Of course, the most immediate example of this type of spending is one of the largest and fastest-growing expenses for retirees: healthcare.

Healthcare represents large, very volatile expenses throughout retirement. Once individuals reach age 70, their households will, on average, incur over $122,000 in out-of-pocket medical spending over the remainder of their lives, while households in the highest percentile of expenditures will incur over $600,000 in medical expenses over their remaining lives (Jones et al. 2018). Unsurprisingly, 45% of adults are concerned they will not be able to afford healthcare when they retire.[2] Required expenses are designed to roughly follow the distribution of out-of-pocket medical expenses by age in Jones et al. (2018) and are summarized in Exhibit 1.

Exhibit 1: Distribution of modeled out-of-pocket healthcare expenses ($000)

Age	65	75	85	95	Lifetime
μ	0.41	0.98	1.37	1.65	
σ	1.34	1.39	1.46	1.51	
Mean	3.1	5.9	9.3	13.2	126
Median	1.5	2.7	3.9	5.2	116
75th percentile	3.6	6.7	10.3	14.2	150
90th percentile	7.8	14.9	23.9	34.0	193
95th percentile	12.1	23.5	38.5	55.8	222

Source: Author's calculations.

Percentiles are expressed in thousands. Lifetime values reflect the Social Security Administration's forward-looking survival rates for a 65-year-old male. The simulation is drawn from a lognormal distribution parameterized by mean μ and variance σ^2.

Unsurprisingly, both the expectation and the variance of out-of-pocket healthcare expenses increase with age. For convenience, healthcare spending is assumed to be independent through time and uncorrelated with mortality. Despite its simplicity, this process recovers a lifetime distribution of out-of-pocket costs near to, or slightly conservative when compared with, their true values (Jones et al. 2018 and Fronstin et al. 2014).

This paper complements the sizable empirical research that demonstrates the wealth and allocation consequences of healthcare expenses (see De Nardi, French and Jones 2010; Coile and Milligan 2009; Rosen and Wu 2004; Poterba, Venti and Wise 2011; Poterba, Venti and Wise 2017), and spending behavior in retirement (Blanchett 2013, Banerjee 2015), by presenting and solving a model of joint expenditure and asset allocation in the presence of uncertain required liabilities. In contrast to typical models, a framework with uncertain required liabilities predicts consumption and asset allocation behavior that far more closely reflects real-world patterns, in our view.

THE MODEL

A retiree chooses a sequence of in-retirement consumption $(\{c_t\}_{t=0}^{T})$ and asset allocations $(\{\phi_t\}_{t=0}^{T})$ to maximize utility subject to uncertain realizations of required expenses each year $(\{h_t\}_{t=0}^{T})$. Utility is defined over consumption only, exponentially discounted (β) and weighted by mortality (π_t).

$$\max_{\{c_t\}_{t=1}^{T},\{\phi_t\}_{t=1}^{T}} \sum_t \beta^t \pi_t E[U(c_t - h_t)].$$

Utility is maximized subject to the period-by-period budget constraint and evolution of the retiree's invested wealth based on stochastic returns to the risky asset μ_t:

$$c_t \leq W_t + SS_t - h_t$$

$$W_{t+1} = W_t(\phi_t \mu_t + 1) - c_t.$$

Here households may truly run out of money with required expenses. If this occurs, they are provided a minimum consumption guarantee[3] set equal to $\bar{c}_t$:

$$h_t > W_t + SS,\ \ \{c_{t+s} - h_{t+s}\}_{s=1}^{T} = \{c_{t+s}\}_{s=1}^{T},$$

$$\{W_{t+s}\}_{s=1}^{T} = 0, \{\phi_{t+s}\}_{s=1}^{T} = 0.$$

1 Edleson. "Almost Half of Americans Fear Running Out of Money in Retirement" (2019)

2 Institute for Healthcare Policy and Innovation, University of Michigan, 2019

3 Brown and Finkelstein (2011)

Of course, with any type of guarantee, it is possible to have a rapid divesting of all assets be the dominant strategy, as this maximizes the value of the guarantee for the remaining years. This is not a widely observed strategy among retirees (nor does it reflect typical advice from financial advisors), suggesting that real-world welfare guarantees represent a rather low level of consumption. As in Part 1 of this series, the consumption guarantee is set to the fifth percentile of income for retirees in the U.S.[4] For simplicity, portfolios are constructed out of two stylized assets: a "risk-free" security that pays a zero rate of return in every state of the world, and a risky investment that pays a positive expected return that is not guaranteed. Here the risky investment is intended to represent equities: The expected return is 3% over the risk-free asset, with an annual volatility of 16%:

$$\mu_t \sim N(3\%, 2.56\%)$$

Required expenses, h_t, are as specified in the previous section. As in the first paper in this series, preferences are expressed as constant relative risk aversion $\left(U(c) = \frac{c^{1-\rho}}{1-\rho}\right)$, with a coefficient of relative risk aversion equal to 4. Individuals discount future consumption at a rate of 2.5% per year (β=0.975), and survival rates are those for a 65-year-old male, truncated at age 105.[5]

Optimal consumption and asset allocation decisions are determined by the retiree's age, level of wealth and required expenses:

$$\phi_t^* = \phi(t, W_t, h_t)$$

$$c_t^* = c(t, W_t, h_t)$$

The solution to this problem is a set of state-dependent functions (typically called controls) that depend on the retiree's age and wealth, and the realized expense requirements. The solution to this model will be presented in three stages with gradually increasing complexity.

Case 1: No required expenses, no Social Security

First, we consider the solution to a more traditional model, without required consumption or Social Security. This case is well known but somewhat unique. Here the optimal asset allocation function can be solved for in closed form (similar to Merton 1969 and 1973). The investor will hold a constant equity allocation throughout equal to

29.2% ($\phi^* = \frac{\mu - r}{\rho\sigma^2} = \frac{0.03}{4(0.16)^2} = 29.2\%$).

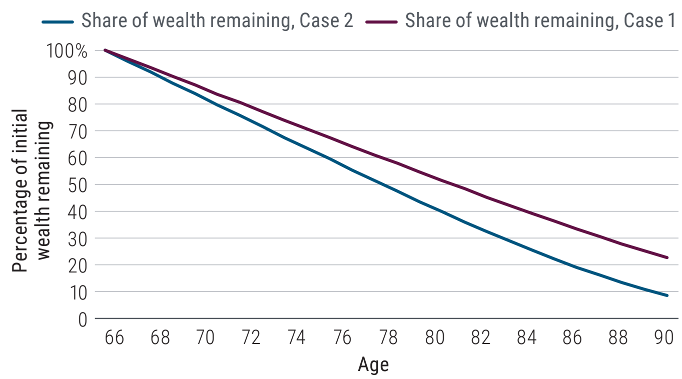
Subsequent cases in this paper cannot be solved analytically and require numerical methods.

Case 2: Including Social Security

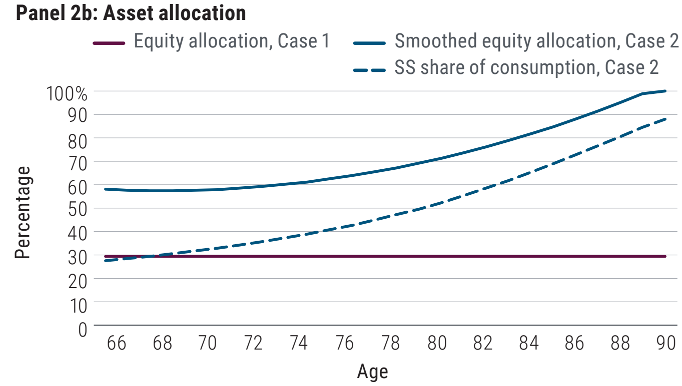
The presence of guaranteed period-by-period income materially changes the incentives facing the retiree. In this first extension, Social Security benefits are provided to the retiree at their 2019 maximum of $34,332 per year. These benefits effectively make the retiree much wealthier: In addition to their financial wealth of $1 million, they now have a substantial stream of guaranteed income.

Exhibit 2: Decumulation rates and asset allocation, Case 1 and Case 2

Panel 2a: Wealth decumulation



Panel 2b: Asset allocation



Source: Author's calculations.

Smoothed allocation represents a quadratic fit of the numerical solutions to remove noise.

4 This seems realistic: Individuals receive long-term-care coverage through Medicaid with very few out-of-pocket costs only after paying a deductible of essentially all their remaining assets. Reasonable changes in this guarantee affect the magnitude of the findings presented in this paper, but not their existence. For example, any guarantees at or below the poverty line would lead to slower wealth drawdown rates than those found in the model without uncertain required consumption.

5 Social Security Administration Actuarial Life Table, 2010. In this paper, analysis is focused on behavior until age 90 to ensure that the results are not driven by boundary issues induced by the numerical solution method, such as the known terminal age and bounded support of the health expense shocks.

This effectively provides them a minimum level of consumption, which tends to accelerate the drawdown rate of their wealth, as shown in Panel 2a of Exhibit 2. At age 82, the retiree in Case 2 (with Social Security) has 25% less financial wealth than the retiree in Case 1 (without Social Security), and this declines to less than 50% at age 88. The asset allocation consequences in Panel 2b are similarly pronounced. Intuitively, Social Security represents a large part of the Case 2 investor's wealth. Invested assets play a smaller role in financing spending with Social Security, so the net effect of asset volatility on total consumption falls in the presence of guaranteed income payments. Panel 2b of Exhibit 2 shows that with these parameters roughly 25%–30% of initial retirement consumption is financed by Social Security payments. Over time, total spending falls and the fraction of consumption sourced from Social Security increases, passing 50% at age 80 and reaching 80% by the retiree's 90th birthday. The volatility of financial wealth has a diminishing impact on the volatility of total consumption over time. Accordingly, the optimal portfolio holds an increasing allocation to equities as the retiree ages, until it is essentially fully invested in risk assets from age 90 onward.

The consumption capital asset pricing model (CCAPM; Rubinstein 1976, Lucas 1978, Breeden 1979) provides another way to understand the relationship between Social Security and optimal asset allocation. In the CCAPM, assets less correlated with consumption are more attractive investments. As the retiree ages, their total consumption is composed increasingly of Social Security and is sourced less from their invested assets. As a result, risky investments become increasingly attractive.[6] The upward-sloping allocation to risk assets is entirely driven by the changing relative importance of Social Security to overall consumption.

Needless to say, increasing investment risk with age is not behavior exhibited by retirees. Averaging across the 1989–2016 data, the Federal Reserve's Survey of Consumer Finances reports the share of financial assets in equities drops from 55% for households ages 55–64 to 48% for households ages 75 or more.[7]

The contradiction between real-world actual allocations in retirement (which modestly decline) and upward-sloping "optimal" equity allocations is well known. In a model very similar to what we saw in Cases 1 and 2, Delorme (2015) and Daverman and O'Hara (2015) show the role that the lack of wage income and the presence of pension income, such as Social Security, play in driving the optimal risk allocations upward. An upward-sloping allocation to risk assets in retirement is a consequence of combining typical retirement income models with the presence of lifetime income streams, such as Social Security. Such an investment profile is not seen in the data, and extremely risky portfolios for the very aged are not often recommended by financial professionals.[8] In contrast, uncertain future expenses lead to more realistic spending and investment behavior, even with guaranteed income and constant risk preferences.

Case 3: Incorporating uncertain required expenses

Next we incorporate spending requirements into the model that follow the distribution shown in Exhibit 1. Optimal consumption and allocation behavior,

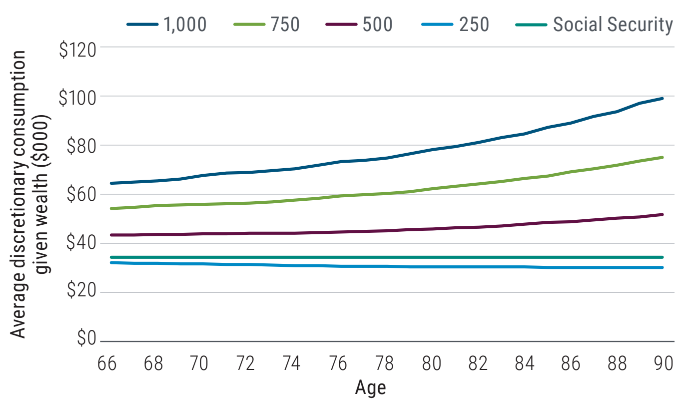
$$c_t^* = c(t, W_t, h_t) \text{ and } \phi_t^* = \phi(t, W_t, h_t),$$

are explored in sequence.

OPTIMAL CONSUMPTION BEHAVIOR

Exhibit 3 shows optimal discretionary consumption behavior. Additional wealth increases optimal consumption at any age. Similarly, any given level of wealth later in life leads to higher consumption, as the retiree is effectively "richer," with fewer expected years of spending to finance. Wealth preservation behavior also is visible in this exhibit: With low enough asset balances, discretionary spending eventually falls below guaranteed Social Security income as retirees decrease consumption in an attempt to increase asset balances.

Exhibit 3: Discretionary consumption by age and wealth



Source: Author's calculations.

Values represent the optimal amount of consumption in excess of required expenses by age for a given level of wealth at that age.

6 This is a more subtle benefit of higher guaranteed income, such as that from deferring Social Security benefits: Total consumption becomes less correlated to the markets, allowing for higher comfortable allocations to risk assets and correspondingly higher expected returns.

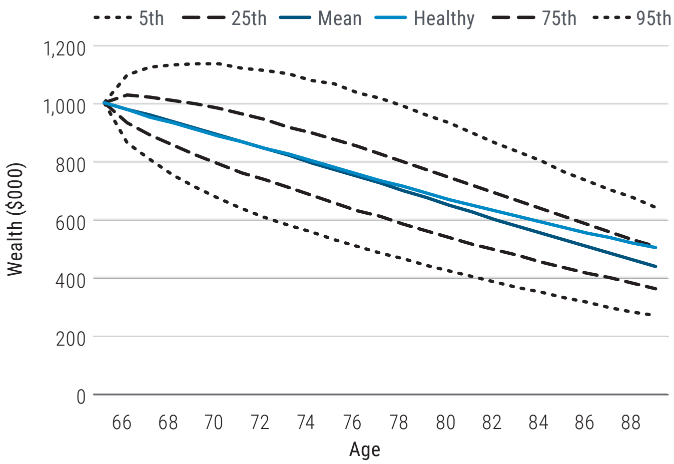
7 Federal Reserve Survey of Consumer Finances. Average from 1989–2016 surveys.

8 Pfau and Kitces (2014) are an exception. Some of their work advocates for an upward-sloping-in-retirement glide path, based on the survival rates of certain spending rules.

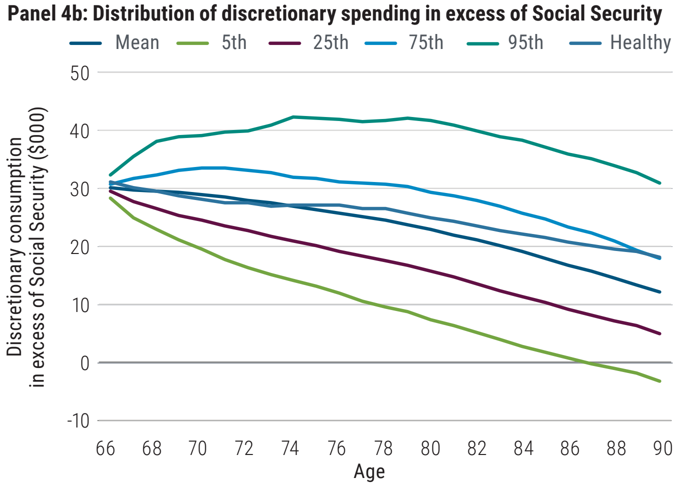
For higher wealth levels, optimal spending (and thus wealth decumulation) rates in this model are generally positive, so that a well-funded retiree expects to slowly spend down their assets over time. Of course, the realized rate is subject to uncertainty in asset returns and expense requirements: Uncertain financial markets and unknown future spending needs combine to create a distribution of spending and wealth that slowly declines over time. Exhibit 4 shows percentiles of the distribution of wealth (Panel 4a) and discretionary consumption financed by wealth (Panel 4b), as well as the path followed by a (very lucky) healthy retiree who never experiences required health expenses and whose investments always receive their expected returns.

Exhibit 4: Distribution of wealth and self-financed discretionary consumption over time

Panel 4a: Distribution of wealth



Panel 4b: Distribution of discretionary spending in excess of Social Security



Source: Author's calculations.

Values represent the percentiles of the distributions of simulated wealth and discretionary consumption financed by wealth. "Healthy" individuals experience no required health expenses and always receive the expected equity returns with zero volatility; these values are smoothed with a moving average to remove artifacts from the grid-based solution.

There are two immediate conclusions. First, as stated above, both wealth and discretionary consumption tend to decline over time; second, they are both quite volatile. The combined impacts of health expenses and asset market shocks on wealth are only partially absorbed by movements in discretionary spending.[9] Both of these predictions agree with the data on wealth and spending patterns in retirement. Excluding healthcare spending, real consumption declines as households age, and households with larger health expenses tend to have smaller asset balances (Rosen and Wu 2004, Ebrahimi 2019, Consumer Expenditure Survey).

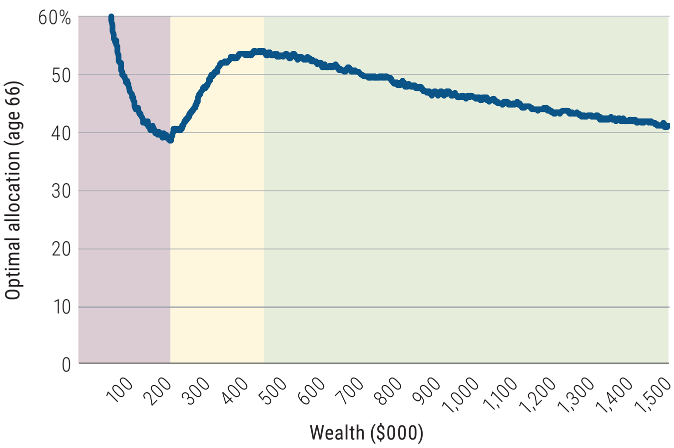
OPTIMAL ASSET ALLOCATION

Optimal asset allocation behavior with required expenses $(\phi_t^* = \phi(t, W_t, h_t)$ is more subtle. Unlike consumption, optimal risk-taking behavior need not have a monotonic relationship with wealth, particularly when current assets are very near the required amount of future funding. If the individual has enough assets, extra risk will increase the probability of a sufficiently bad outcome and decrease the chances that they can meet their funding requirements. If, however, they have too little wealth, extra risk increases the chance of a sufficiently positive outcome to meet their funding requirements. This may seem counterintuitive, but this relationship is surprisingly common. For example, increasingly risky strategies are often chosen in sports when a loss is otherwise assured: Pulling a goalie in ice hockey or immediately fouling in basketball are high risk strategies with very high variance (and negative expected returns). These sorts of strategies are typically seen from the losing team near the end of the game, when a loss is almost certain, but never implemented by a team in the lead. Similarly, when wealth levels fall below anticipated future spending needs, risk-taking becomes increasingly attractive, as it provides a greater chance of sufficient funding in future periods.

9 The unconditional wealth distribution initially widens, then narrows later in retirement as retirees adjust their period-by-period consumption and attempt to maintain a level of future wealth that allows for continued self-insurance against future risks. This is seen most clearly with the "healthy" retiree, whose wealth and consumption do not materially deviate from the mean trajectory until 10 to 15 years into retirement. Only at this point does the healthy retiree's consumption increase, as their excess wealth is finally consumed rather than saved. Consistent with this, the distribution of wealth in Exhibit 4 begins to narrow at age 75, even though the volatility of healthcare expenses grows rapidly well beyond this point.

This pattern is borne out in the model's results, as shown in Exhibit 5. When wealth is high relative to future needs (in the green region), decreases in wealth slowly increase the optimal equity allocation, as the risk of underfunding is low and Social Security plays a larger role in total consumption, as we saw in Case 2. (The 95th percentile lifetime required consumption is $222,000, per Exhibit 1.)

Exhibit 5: Nonmonotone wealth allocation relationship early in retirement

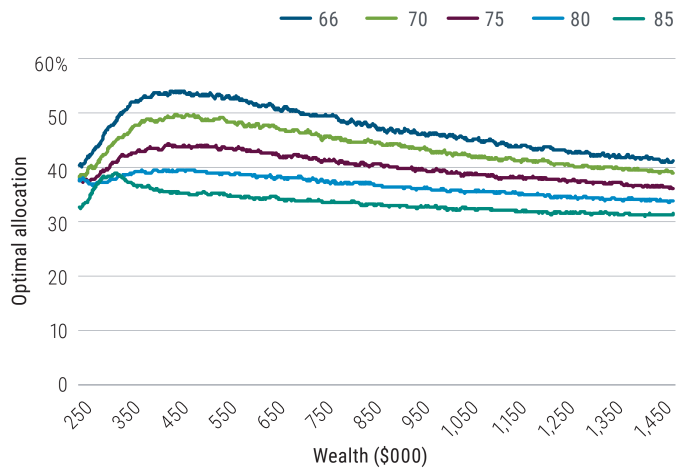


Source: Author's calculations.

Values are smoothed with a moving average to remove artifacts from the grid-based solution.

However, as wealth declines further, funding risk gradually increases. Eventually, as wealth nears the amount necessary to fund future required expenses, optimal allocations begin to fall. In this range – approximately $200,000 to $450,000 for a 66-year-old and denoted in yellow in Exhibit 5 – the increased risk of failure from higher portfolio volatility outweighs the Social Security effect, and the net appeal of risky investment is diminished. Finally, for wealth levels that fall below future required expenses – less than $250,000 and marked in red in the exhibit – additional risk lowers the risk of failure in the future and is increasingly attractive. The magnitude and timing of this relationship evolve over time, as older retirees have fewer periods before they face the potential of large required expenses. In Exhibit 6, we show the optimal equity allocation for ages 66, 70, 75, 80 and 85 for retirees who appear "funded," with wealth beyond $250,000.

Exhibit 6: Wealth allocation relationship by age for funded retirees



Source: Author's calculations.

Values are smoothed with a moving average to remove artifacts from the grid-based solution.

As retirees age and spend their assets, they move down between the curves in Exhibit 6. The ultimate relationship between asset allocation and age is a function of how quickly wealth is spent down (how rapidly the individual moves toward the origin). There is a wide range of potential dynamics here: Consider a household with wealth levels near the median of $250,000.[10] These households likely have sufficient wealth to cover their future medical expenses, though they are relatively close to the funding boundary (approximately $250,000 to $450,000, as in Exhibit 5), and declines in wealth lower the appeal of equities. These results suggest that such households will hold approximately 40% in equities. Moreover, as Exhibit 3 shows, these households may actually consume slightly less than their Social Security payments to preserve their savings for unknown future expenses. If markets perform well, the extra returns plus these extra savings will increase the households' wealth and drive up their optimal allocation. A market downturn will have the opposite effect: lowering their wealth, making equity risk less attractive at the margin and leading to a reduction in risk asset exposures. That is, a retiree in this region will increase exposure to equities after a rally and reduce it after a drawdown – exactly the sort of "buy high, sell low" behavior among retail investors that is so often denounced. Here, though, such trading would likely be optimal, given the nature of the risks they face.

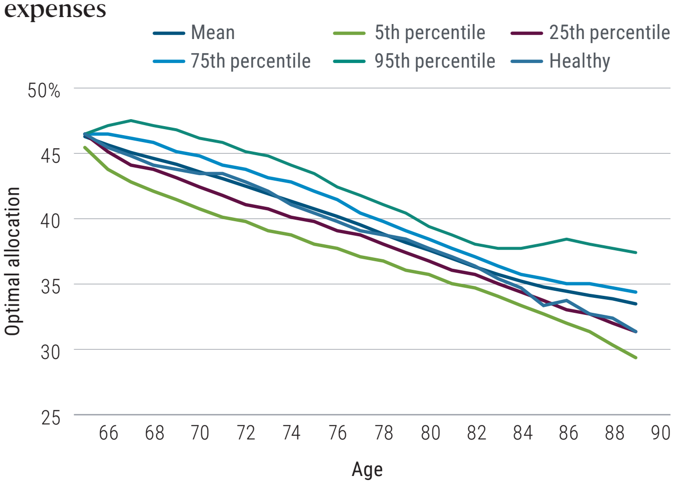
10 Federal Reserve Board, 2016 Survey of Consumer Finances. Median net worth for 65–74-years old and 75 years old and over households is $223,400 and $264,800, respectively.

These results suggest that, in addition to lowering current and future consumption to preserve wealth, as discussed in the first part of this series (Klein 2020), the reduction in wealth from required expenses will lead to less risky asset allocations for many moderate net worth households or those with higher anticipated healthcare spending needs, as documented in Rosen and Wu (2004) and Poterba, Venti and Wise (2017).

A DE-RISKING ASSET ALLOCATION THROUGH TIME

With $1 million in initial financial wealth, the retiree's joint consumption and wealth decumulation behavior is such that the optimal equity allocation tends to decline slowly with age. Compared with the volatility of discretionary consumption (in Exhibit 4), the range of acceptable asset allocations is rather narrow: The difference between the lowest and highest is only 5 to 10 percentage points throughout the early and middle retirement years as shown in Exhibit 7.

Exhibit 7: In-retirement glide path with uncertain expenses



Source: Author's calculations.

Values are smoothed with a moving average to remove artifacts induced from the grid-based solution. "Healthy" individuals experience no required health expenses and always receive the expected equity returns with zero volatility.

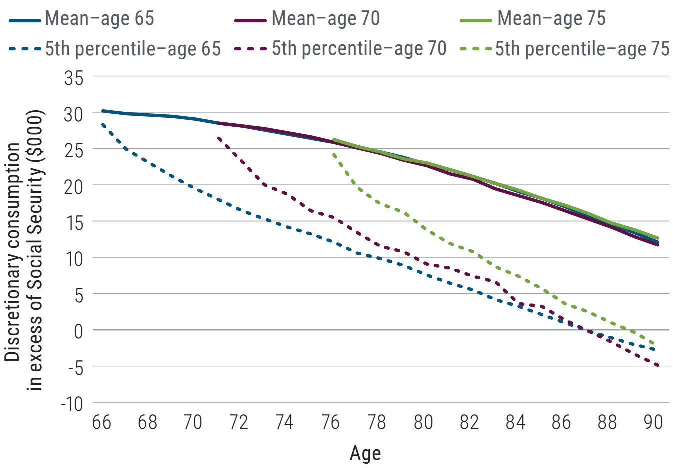
Volatile consumption, annuities and rolling ladder strategies

Uncertain required spending no longer makes constant consumption the most desirable outcome. Instead, spending behavior will rise and fall with markets and individual circumstances. Such variation is sensible but immediately limits the appeal of steady income streams. In a model that excludes uncertain required spending, annuities are nearly ideal investment products. Here they can still be attractive, but their appeal may be more as an investment that harvests an increasing survival premium than as a way to guarantee fixed total consumption for many years. If actuarially fair, one-period-ahead annuities would still be ideal investments (Brown et al. 2005, Peng and Warshawsky 2010), as the guaranteed return is inversely proportional to ever-declining survival rates. Of course, annuities are not actuarially fair. Using the survival rates in this paper, a one-period annuity's return will exceed a 3% equity risk premium once the individual reaches age 73, but it cannot overcome an 85% money's worth (the average value from Brown et al. 2000) until the retiree reaches age 90. An annuity targeted toward harvesting high survival premia that spreads the money's worth costs over several years, such as a deferred, or longevity, annuity, seems appealing because of the high return. However, this return must be weighed against desired future consumption, which is steadily falling and may not always exceed other sources of income. We can see this in Panel 4b of Exhibit 4: Even with $1 million in starting wealth, in the very worst scenarios consumption need not exceed Social Security benefits 20 years into retirement.

A retiree in this model expects to enjoy substantial consumption beyond their Social Security benefits, on average, particularly early in retirement. As the retiree ages, they face a distribution of possible future total consumption financed from the investment portfolio (as in Exhibit 4) such that in the worst cases they will have no discretionary spending beyond their Social Security benefits. The size and shape of the distribution of their future spending are a function of the distribution of required future expenses, and their wealth – itself determined by realized market returns, Social Security payments and the history of their overall portfolio allocation. Assuming the term premium is not extremely negative (indeed, it is usually positive), a risk-averse retiree would at least want to ensure the lower bound of the distribution of future consumption on a rolling basis.

Exhibit 8 shows the distribution of future consumption for retirees aged 65, 70 and 75, conditional on their remaining wealth being within $10,000 of the mean value expected at that age.

Exhibit 8: Conditional distribution of future consumption financed by wealth, ages 65, 70 and 75



Source: Author's calculations.

Values are smoothed with a moving average to remove artifacts induced from the grid-based solution. For the age 70 and 75 values, the sample is restricted to the 2%–3% of paths with simulated wealth at the indicated age within $10,000 of the mean value.

At age 66, the fifth percentile of consumption begins at nearly $30,000 and declines until it reaches zero near age 85, even though at this age expected consumption is $15,000 to $20,000 higher. Once the retiree reaches age 70, the forward-looking distribution widens more rapidly. Conditional on the retiree having close to the mean level of wealth at age 70, the fifth percentile again begins near the mean, but it declines to zero at nearly the same age as in the unconditional distribution. This suggests that rolling, shorter-term, partial consumption immunization strategies are preferred in a world with uncertain future expenses.[11] Rather than support constant spending for life, the retiree would want assets that generated payments equal to conservative percentiles of their anticipated spending. As an example, a rolling, intermediate-term bond ladder may be a more attractive way to support decreasing future spending than would an immediate annuity. The height and length of the ladder would evolve as the investor moved through retirement and uncertainty (in both the markets and their own expense needs) was resolved.

Finally, Exhibit 8 shows that, in addition to helping to protect different amounts of real income each year, investment strategies should slowly shorten their maturity over time. As the retiree ages, they steadily approach the possibility of immediate, large required expenses. An increased potential need for short-term cash reduces the appeal of investments that protect consumption well into the future. In the exhibit, the tail percentiles steepen as the retiree ages. As a result, investments following this distribution would shorten maturities over time. Using the positive portion of the fifth percentile in Exhibit 8 as a guide, weighted average spending moves from 7.25 years in the future at age 66 to 6.0 at age 70 and 4.7 years at age 75.

11 Of course, the desired amount of future consumption to protect is a function of capital market assumptions, particularly the term premium and the covariance between investable assets and future consumption needs.

CONCLUSION

A top self-reported concern is that individuals may run out of money in their retirement or otherwise be unable to afford their expenses. Typical economic models do not easily permit these sorts of statements. In this paper, the traditional retirement model is augmented with unknown required future expenses. These expenses can be thought of as an approximation to uncertainty over future preferences or random future states in which the marginal utility of consumption is very high, such as required repairs, taxes or – the example explored in this paper – out-of-pocket healthcare spending. Though these idiosyncratic risks cannot be hedged in the financial markets, this does not mean that they will not affect consumption and investment behavior.

With the inclusion of unknown required future liabilities, model predictions reflect actual retiree behavior much more closely. The first paper in this series found that wealth would be spent much more slowly and consumption would be more volatile, relative to the canonical model, to preserve assets for risks that might be faced later in retirement. Similarly, annuities would be less attractive, particularly for those with higher risk aversion and longer life expectancies – exactly those who would most enjoy annuities under traditional models.

This paper extends the framework to investigate asset allocation. In traditional models, the presence of Social Security or other guaranteed pension benefits typically results in asset allocations that continually increase their portfolios' risk as retirees age – yet another result not seen in the data. With uncertain liabilities, the optimal asset allocation is determined by whether the retiree has enough wealth relative to the distribution of future risks.

Including uncertain required future expenses generates several predictions that more closely reflect real-world investment behavior:

- Non-healthcare-related spending should fall as the retiree ages, while spending on healthcare should increase.
- Spending in retirement should display some volatility to help preserve assets and protect against potential future risks.
- For retirees with enough wealth, the optimal asset allocation should slowly de-risk over time.
- Annuities or deferred annuities may not be attractive investments, even in the face of large positive survival premia.
- Instead, when future consumption is increasingly uncertain over time, rolling, shorter-term investment strategies that gradually shorten over time, such as a bond ladder, may be more suited to the retiree's needs.

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CMR2020-0508-1181544

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