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SURVEYS AND CROSSOVER

This section provides surveys of the literature in investment management or short papers exemplifying advances in finance that arise from the confluence with other fields. This section acknowledges current trends in technology, and the cross-disciplinary nature of the investment management business, while directing the reader to interesting and important recent work.

THE F-UTILITY OF WEALTH: IT'S ALL RELATIVE

Arun Muralidhar[*,a]

Finance theory is based on a very simple, yet critical assumption that "individuals maximize the expected utility of wealth". However, there are three crucial elements of this simple six-word phrase that does not really stand the test of what investors actually do and one could argue that the incorrect use of Modern Portfolio Theory (MPT) has led to the looming global retirement crisis. First, investors care about relative wealth (i.e., wealth relative to a goal) rather than absolute wealth, popularly called "Goals-Based Investing". Second, individuals (or principals) are not always the ultimate decision-makers—rather, many investment decisions are delegated to agents, which distorts behavior. Third, and most crucially, most investors do not appear to focus on utility functions, but rather seek to maximize risk-adjusted return. Instead, finance theory should start with the assumption that "investors delegate to maximize relative risk-adjusted returns." This paper seeks to show how incorporating these three simple and completely realistic changes impacts asset pricing, asset allocation, and the correct use of risk-adjusted performance measures. While the initial step requires a rethink of finance theory and models, the more urgent goal is to ensure retirement security as this new approach leads to financial innovation, better regulation, investments and retirement outcomes.

*Arun Muralidhar is co-founder of M-cube Investment Technologies LLC and AlphaEngine Global Investment Solutions LLC, and also serves as Adjunct Professor of Finance at George Washington University. These are personal views of the author and all errors are mine.
[a]Founder of M[cube] Investment Technologies and AlphaEngine Global Investment Solutions, Address: 9603 Georgetown Pike, Great Falls, VA 2206, USA. E-mail: arunmcube@gmail.com; Phone: 703-759-0264.

If a man is proud of his wealth, he should not be praised until it is known how he employs it.
Socrates[1]

In their Nobel Prize lectures, Sharpe (1990, p. 315) and Markowitz (1990, p. 281) posit that traditional finance theory is based on a very simple, yet critical, assumption that "individuals

maximize the (expected) utility of wealth".[2] Three crucial elements—"wealth", "individuals", and "maximize utility"—of this six-word phrase do not match reality. More critically, the likely erroneous use of Modern Portfolio Theory (MPT) by pension funds and regulators, that overlooked the nuance of these assumptions, may have led to the looming global retirement crisis. This paper highlights the challenge of the MPT-inspired methods currently employed to manage and regulate pension funds. It suggests an alternative path with a more practical restatement of the primary assumption.

To begin, take the first of the three key words: "wealth". Financial experts often overlook Socrates' profound insight. "Goals-Based Investing" (GBI) has brought a greater recognition that investors focus on relative (vis-a-vis goals or liabilities), rather than absolute, wealth (Merton, 2014). Using Socratic logic, an individual with $2 million in assets (or "wealth") and $3 million in liabilities should not be praised as much as an individual with $50,000 in wealth and zero liabilities. Second, "individuals" (or principals) are not always the ultimate decision-makers in financial markets—many investment decisions are delegated to agents, which often distorts behavior, not captured in the seminal MPT papers. Third, and most crucially, investors do not maximize (or even articulate) "utility" functions, but rather seek to maximize risk-adjusted returns (Markowitz, 1990).

This paper seeks to show how incorporating these three simple and completely realistic changes (relative wealth, agency, and maximizing risk-adjusted returns) impact three key aspects of investment: asset allocation, asset pricing, and the correct use of risk-adjusted performance measures. Restating the original six-word phrase, as "individuals delegate to maximize risk-adjusted relative-returns," may require rethinking finance theory, but the more urgent goal is to ensure retirement security. This new approach results in financial innovation, and better regulation, investments, and retirement outcomes.

1 What investors need from effective finance theory

Every individual/pension fund needs effective, robust methodology to set asset allocation, as allocation accounts for 80–90% of the fund's return variability (Brinson *et al.*, 1986). Typically, the key inputs used to derive asset allocation are expected returns (and volatility and correlation) of assets; hence, these inputs should come from robust asset-pricing models. Thereafter, once assets are invested, the fiduciary/principal calculates the risk-adjusted performance of various decisions, ideally, ensuring the agents and the principal are adequately compensated for taking risk.

MPT, for its assumptions, ensures a consistent approach and offers the most elegant models for asset allocation, asset pricing, and risk-adjusted performance. Markowitz (1952) provides a simple portfolio selection methodology, commonly referred to as Mean–Variance Optimization (MVO), to derive optimal risky portfolios (with highest returns per unit of risk), and identify the "risky market portfolio". Tobin (1958) extended Markowitz (1952) to provide a simple asset allocation model, called Two Fund Separation (2FS); namely, all investors should split their assets between the risk-free asset and risky market portfolio, with one's risk aversion establishing the ideal mix of the two. This, in turn, led to a series of innovations in the early 1960s, resulting in the "Capital Asset Pricing Model"[3] or CAPM, which provided a simple formula to derive the expected return of all assets—a key input in MVO. The third leg of the puzzle—effective risk-adjusted performance

measures—was provided by the Sharpe ratio (Sharpe, 1994)[4] and further extended by M-square (Modigliani and Modigliani, 1997).[5]

MPT is widely critiqued—ranging from the behavioral critique to those suggesting that it does not test well empirically—but no other model is as elegant, robust, and internally consistent in providing effective recommendations for these three facets. Perold (2004) reinforces MPT's strength and demonstrates that one could start from a "maximize utility" approach and derive 2FS, CAPM, and the Sharpe ratio, or alternatively, start with "maximize the Sharpe ratio" and then derive CAPM (as in Lintner, 1965) and 2FS, without truly specifying the utility function.[6] Other models typically do not achieve this impressive duality of approach.

2 The looming retirement crisis

MPT gained widespread acceptance because of its elegance, and pension funds globally use its asset allocation, asset pricing, and risk-adjusted performance facets.[7] The real puzzle is: If MPT is so robust and widespread, why do we have a looming global retirement crisis? The funded status, defined as a ratio of assets to liabilities, of both public and corporate US defined benefit (DB) pension funds as of 2017, declined to less than 85%—for every $1 of liability, there is less than 85 cents in assets to pay for it![8] There are similar funding issues with multi-employer plans. Interestingly, Munnell *et al.* (2015) ask: "How did State and Local Funds Become Underfunded?" They found that public DB pension plans funded status was estimated above 100% in 2000, only to decline dramatically in the subsequent 15 years (and beyond). The decline is not limited to US public DB funds; the same is true of US corporate DB plans (and even DB plans in the UK and Japan). By some estimates, the funding gap in the employer-provided US public DB segment is estimated at a minimum of $1 trillion, while some estimates value it closer to $4 trillion.[9] Interestingly, the difference in these estimates comes from the use of different discount rates, an issue probably caused by MPT, discussed later. Pension plans in Canada, Denmark, and the Netherlands are outliers—they achieved funded status close to 100%, because they adjusted their MPT approaches (by focusing on "relative wealth") after the Tech Bubble burst.

Merton (2007) notes that these plans were doomed from the start because their risk was mispriced,[10] but hidden from view with a booming stock market. Many employers—corporate and government—exited the DB pension fund business, due to the decline in funded status post the Tech Bubble and Great Financial Crisis, and retirement risk is increasingly being transferred to individuals in DC plans. Further, some DB funds in the US (and even the Netherlands) may need to lower pension benefits to improve solvency, in turn lowering the welfare of retirees.[11] In the developing world, challenges with funding the public Social Security pillar[12] caused many countries to push individuals into privatized DC plans (Modigliani and Muralidhar, 2004). Private vendors in these pension systems use MPT approaches to manage portfolios, and there is no doubt that these systems are likely to deliver highly uncertain retirement outcomes to individuals (Merton, 2014). In the US, "robo-advisors" have exceeded $200 billion in assets[13] and most, if not all, use MPT approaches, largely ignoring goals.[14]

This begs the fundamental question: If investors were using MPT techniques, how did pension funds go from having enough assets to pay off obligations in 2000 to fighting the tide of a fast-growing deficit 20 years later? Aubry *et al.* (2018, p. 2), in examining 180 public plans over the 2001–2017 period provide a hint to the cause: "over this same 17-year period, all plans,

regardless of their cohort, have underperformed relative to their actuarial investment assumptions, with underperformance being greater for the lower-funded plans." One could throw out many possibilities for this looming global retirement challenge, including: insufficient savings, gross incompetence (highly unlikely given the global phenomenon), inadequate regulation (a likely candidate), poor forecasts of returns (Housel, 2015; Economist, 2015), or using the wrong model to manage pension assets. We argue that the last three are inter-connected, but the most serious is the incorrect use of MPT for managing pension funds (or GBI). MPT assumes a highly stylized situation, inconsistent with the challenge of managing a pension fund (or stochastic goal). Investors and regulators who did not adapt their models and investment approach to the reality of investing have, unfortunately, contributed to the looming retirement crisis.

3 Wealth—absolute versus relative—and importance of goals

The first challenge with the traditional MPT is its focus on absolute wealth. Socrates was correct in pointing out that wealth is valuable only for what it can be "employed." Therefore, wealth maximization is probably the wrong objective for many investors, definitely pension investors. They must worry about relative wealth (i.e., wealth adjusted by liabilities or funded status). Investors have very specific goals for which they accumulate wealth, from saving for retirement and health expenses to financing a child's college education, and each can have un/certain future cash flows. Investors who adopt naïve MPT approaches are ignoring investment goals and focusing solely on wealth maximization. The Dutch and Danes, on the other hand, adapted post-Tech Bubble and focused on protecting relative wealth (i.e., funded status).

Saving for retirement versus saving for college are very different goals. Cash flows for retirement begin when individuals reach 65 years, could continue indefinitely, and should be indexed to, for example, standard-of-living. Saving for college, however, requires cash flows when a child turns 18, is needed for four years, and should be indexed to tuition inflation. One cannot use an MVO optimization approach, which assumes each goal has a unique expected return, because they are truly different cash flow streams, with unique characteristics and time frames. Merton (2014) advocates that retirement investors should focus on maximizing funded status, as opposed to maximizing wealth (or assets), and shows, from a GBI perspective, the "safe" asset in MPT is now risky.[15] This simple twist in perspective allows us to forecast a likely crisis in DC plans globally as most if not all assets in US DC plan portfolios are risky relative to the goal. The Socratic irony is that even the DB pension industry tends to report periodic returns of funds and compares pension fund performance to peers, with little regard to funded status. The investment industry awards innovation prizes to funds with the largest assets, rarely to those with the best funded status—an inadvertent consequence of using an MPT-biased lens for a relative wealth world.

Awareness of the importance of liabilities is not new. Sharpe and Tint (1990) established liability-focused asset allocation for pension funds and showed how it differed from 2FS, especially since no one seemed to use 2FS. However, they did not go the additional step to show how asset pricing would be affected by liabilities (especially if asset allocation is liability-focused).[16] Waring and Whitney (2009), using the Black (1972) Zero-Beta CAPM,[17] assume that investors should maximize the utility of surplus (or assets minus liabilities) and derive an asset-pricing model—from which one can derive a variant of 2FS. Muralidhar *et al.* (2015)—hereafter

MOS—following Sharpe and Tint (1990) and Merton (2014), focus on maximizing the utility of funded status, and similarly derive a liability-centric asset-pricing and asset allocation model they call Relative Asset Pricing Model (RAPM), which replaces 2FS with Three Fund Separation (3FS). In 3FS, allocations are split between the liability hedge (or relative risk-free asset), "risky"[18] assets, and the traditional risk-free asset.

MOS demonstrates that CAPM is a special case of RAPM—CAPM assumes that the liability is deterministic and 3FS is reduced to 2FS, where relative and absolute risk-free assets are not differentiated. In short, path-breaking MPT authors in the 1950s–1970s made a critical, implicit assumption about the deterministic nature of goals, overlooking the Socratic insight about relative wealth. Investors naively adopting MPT (either with a naïve MVO to set asset allocation or using CAPM for forecasts) implicitly accepted the assumption that liabilities are deterministic—which was proven wrong in 2000–2002 (Tech Bubble bursting), 2008 (Great Financial Crisis), and again in Q4 2018—as equity-heavy pension portfolios displayed enormous risk relative to stochastic, bond-like liability profiles, and led to the declines in funded status.

In a relative wealth world, it can be easily shown that the risk-adjusted performance measure corresponding to the (a) Zero-Beta CAPM or Waring and Whitney (2009) is the GH1 or GH2 of Graham and Harvey (1994); and (b) RAPM would be the Sharpe ratio of excess returns of assets over liabilities (i.e., Information Ratio or Differential Sharpe). Risk-adjusted performance measures like the GH1, GH2, or Information Ratio/Differential Sharpe allow the benchmark volatility to be non-zero (as is the case in the Black Zero-Beta CAPM and MOS), and hence would be suited to a situation where the "liability" or goal is stochastic.

Briefly, if investors make decisions relative to stochastic goals, then asset allocation, asset pricing, and risk-adjusted performance must be liability-centric. However, all relative wealth models ignore the rampant delegation of decisions, rendering them incomplete for use by the pension industry or investors in general.

4 Individuals (principals) versus delegated agents

The second major sticking point is assuming "individuals" as the decision-makers in these models (Allen, 2001). Typically, individuals (in the retail space) and even Board members of pension funds do not have adequate expertise to manage assets. As principals, they often hire multiple agents to manage their portfolios. Delegation switches the key parameter of risk from absolute risk (e.g., volatility) to relative risk (or tracking error). A recent example of an institution clearly articulating relative risk parameters for delegation comes from the New Mexico Public Employees Retirement Association (NMPERA). NMPERA explicitly states that the Board established a 10.5% annualized target volatility for the strategic asset allocation (SAA) and a 1.5% annualized tracking error for all delegated decisions.[19] NMPERA is a good example of a fund that understands the risk of delegation, but not all funds are as explicit about their risk targets.

As the principal–agent literature demonstrates, principals cannot observe agents' effort and, in investments, they typically only observe realized returns. There is a lot of noise in performance data and no guarantee of an agent's skill, even if they outperform benchmarks (Ambarish and Seigel, 1996). Limiting relative risk taken by agents as in the case of NMPERA is one way to protect the fund from a rogue/unskilled agent, especially when evaluation periods are long and fee schedules one-sided—if asset managers do well, they get compensated well; if asset managers lose

money, however, the investor (or principal) bears the loss.

Brennan (1993) was the first to examine the implications of asset pricing and asset allocation in the presence of agents, followed by Cornell and Roll (2005). Both papers take the benchmark as given (as opposed to recognizing that the benchmark should be the goal[20]) and do not address the issue of risk-adjusted performance or the agent's skill. In these models, there is no limit to relative risk—very unlikely in real life. Much like Sharpe and Tint (1990) and MOS, agency literature shows that asset pricing is influenced by the benchmark, and the recommended asset allocation is 3FS (i.e., assets split between the benchmark, risk-free asset, and market portfolio). Since agency transforms the risk measure to tracking error, the risk-adjusted performance measure shifts from the Sharpe to Information Ratio or, alternatively, for those who prefer M-square, the agency-based version is M-cube.[21] M-cube (Muralidhar, 2000) is shown to dominate M-square when principals delegate to agents as M-cube is the only risk-adjusted performance measure that ranks investments or agents identical to measures based on skill (Ambarish and Seigel, 1996).

The main take-away from agency literature and delegation in practice is that asset allocation, asset pricing, and risk-adjusted performance measures should be benchmark-centric, and more importantly, must clearly recognize that investors have limited, very specific, relative risk budgets that they allocate to agents. Moreover, with funded status declining among pension funds, the focus is increasingly on fees, with investors only willing to pay for skill and risk-adjusted excess returns. Hence, any effective agency-based model must incorporate a principal's desire for skilled agents and not assume that agents can take unlimited risk. However, the NMPERA risk budget shows, in terms of relative importance, that the tolerance for relative wealth (SAA) risk at 10.5% dominates tolerance for agency risk at 1.5%.[22]

5 Maximize utility or risk-adjusted performance?

Finance and microeconomic theory makes the assumption that individuals maximize (expected) utility. While it is a very appealing theoretical construct, no investor is able to articulate their true utility function or risk aversion parameter (Markowitz, 1990, p. 285). Most investors can, however, articulate a target expected return for a given level of risk (as in MVO) or, alternatively, a desire to maximize risk-adjusted portfolio performance, as in the NMPERA example, which is not an isolated case. The Los Angeles County Employees' Retirement Association (LACERA) Investment Policy (IPS) states: "The Fund's long-term performance objective is to generate risk-adjusted returns that meet or exceed its defined actuarial target as well as its policy benchmark, net of fees, over the Fund's designated investment time horizon."[23] LACERA, like NMPERA, also articulates a relative risk budget, but there is no mention of "utility" in the statement of the objective.

Modigliani and Modigliani (1997) and Muralidhar (2000) demonstrate how to extract asset allocation recommendations from risk-adjusted performance measures for principals and delegated agents, respectively. Muralidhar and Shin (2013) extend the original M-cube approach, assume a liability benchmark and delegation to an agent, and show how asset allocation to the three assets (liability hedge, risky portfolio, and risk-free asset) change based on the relative risk target. However, unlike Perold (2004), no one has yet been able to map these new liability and agent-incorporated aspects into a utility function or create a complete asset- pricing model based on maximizing (relative) utility assuming

delegation. Until such a breakthrough is made, this approach will probably not gain acceptance among academics who approach theory from a utility perspective. Prof. Merton noted (in private correspondence) that finance theory would require an extremely complex utility function to incorporate bespoke streams of goal cash flows in a universe of many investors (i.e., leading to different risk-free and risky assets for each goal).[24] This may be an intractable problem and a challenge for academics to ensure that theory reflects reality, but it is critical, given the importance of retirement security. At a minimum, however, the six-word starting assumption needs to be restated: "Investors delegate to maximize risk-adjusted relative-returns."[25]

6 Implications for practice and global retirement security

All these theoretical nuances come to a head in pension fund regulation, and until many of the implications of these assumptions are underscored and, ideally, corrected, things will not end well. Regulation is key, because it determines asset allocation. Aubry and Crawford (2019) note that, "From 2001–2008, the average allocation to fixed income, stocks, and other non-traditional asset classes—alternatives such as private equity, hedge funds, and real estate—was roughly the same for public and private plans. However, from 2009–2015, the allocations diverged, with public plans investing a significantly larger share in risky assets than private plans." One can easily demonstrate how the divergence in regulation in private and public DB pension plans led to this divergence in asset allocation as corporate DB plans were increasingly required (by regulation) to hedge the duration of their pension liabilities. On the other hand, there has been no change in public DB plan regulation over this period.

First, as Merton (2014) notes, DC funds in the US are heading for a major problem. US asset managers who offer "Target Date Funds" are given "safe harbor" from legal liability by the US regulator—these products that rotate more into bonds as one ages have apparently been deemed "safe," though they provide no guarantee to investors of either wealth level or retirement income. The presumption of "safety" comes from the incorrect belief that asset managers rotate client portfolios into assets that engender less wealth volatility as one ages (or the "risk-free" asset in traditional MPT). Many countries and several US states that are defaulting uncovered individuals into DC plans run the risk of compounding this error (Muralidhar, 2018). In short, DC regulation should be funded status or retirement income-focused, not wealth-focused, an idea being considered by regulators in the developing world.

Second, challenges with DB plans persist. Two US DB pension funds—corporate and public—with identical liability cash flows and assets can have completely different measurements of funded status. Public funds value liabilities using the expected return of assets (ala Markowitz, 1952) for discounting, and corporate funds discount cash flows (post the Tech Bubble only)[26] using a more generic liability-replicating curve (ala Sharpe and Tint, 1990). Worse still, two US public DB funds with identical liabilities cash flows could have different liability valuations because they could use different expected returns. Since it is never explicitly stated that original MPT models assume that liabilities are deterministic, US DB pensions have widely differing approaches to evaluating liabilities (and setting asset allocation). This difference in discount rate also leads to different estimates of the looming pension deficit noted earlier.

To answer the question that Munnell *et al.* (2015) raise about the decline in funded status in public funds, and their observation that investment

returns are a major contributor to the problem: While a fund may discount liabilities with an expected return, there is no asset or allocation that guarantees that same return. As a result, US public DB pensions cannot, try as they might, ever hedge their (regulatory) liabilities, which may explain the long-term underperformance of actuarial targets, as noted by Aubry *et al.* (2018). Stated differently, no one can guarantee, try as they might, that the SAA has any chance of achieving a fund's expected return (or discount rate for liabilities). In short, public funds have been influenced and hampered by this regulatory nuance. Until this issue is addressed, public DB pensions will face major challenges, as they continue to take unmanageable risks relative to their regulatory liabilities. These pension funds could hedge their liability cash flows once they are overfunded, as in 2000, as recommended in Sharpe and Tint (1990). However, if they continue to use traditional MVO (or current regulation), there would never be a reason to hedge their cash flows even if they get overfunded. On the other side of the pond, Dutch and Danish regulators specify a mandatory liability valuation curve for all funds. Why does this matter? The proof is in the pudding—Dutch pension funds have an average funded status above 100%[27]; their US counterparts skirt the 85% range following a 10-year bull market in stocks! Hence, it is imperative to adopt transparent liability-centric regulation, derived from a liability-centric asset allocation, asset-pricing, and risk-adjusted performance approach.

Third, pension fund evaluation should not be based on returns, but on funded status. Investors and asset managers should be compensated on skill and risk-adjusted outperformance relative to their respective benchmarks, not on short-term absolute performance. Until this changes, investors will have no incentive to boost funded status—which is the true measure of solvency of the pension fund.

Fourth, this revised approach could have implications for monetary and fiscal policy and macroeconomic theory. Merton and Muralidhar (2015) show that lowering rates, widely believed to stimulate consumption and investment, led to big declines in the funded status of pensions (as liabilities rose more than assets). While wealth rose, relative wealth declined! Employers were forced to contribute to corporate pension funds, muting the impact on consumption and investment. The 2017 US tax reform had an unintended outcome in this relative wealth world—corporations have greater incentive to contribute to their pension funds, instead of paying dividends or investing in new capital, resulting in limited future growth from "stimulative" fiscal and monetary policy.

Finally, the GBI "risk-free" asset is different from the MPT "risk-free asset" and necessitates innovation in financial instruments. The true risk-free asset for DC pensions is not a generic bond portfolio, but rather an annuity that provides investors with guaranteed real cash flows until death. Annuities provide such a profile, but, even if given "safe harbor", are illiquid, costly and complex. Hence, Merton and Muralidhar (2017) recommend the creation of a new, liquid bond issued by the government and other entities that reflects the precise goal-required profile of retirement cash flows. Creating such an instrument greatly simplifies retirement planning for even the most financially unsophisticated individual.[28]

7 It's all relative

In summary, finance theory makes a series of simplifying, implicit assumptions in the pithy statement: "Individuals maximize the (expected) utility of wealth." Resulting MPT models were elegant, internally consistent, and pathbreaking, earning the authors Nobel Prizes, but there is a big gap between the world assumed by these early academics and the real world today.

Unfortunately, MPT approaches used to manage and regulate portfolios with stochastic liabilities and rampant delegation do not augur well for future retirement security. This paper is a call to arms for academics and practitioners to revisit many of these models and approach them from the perspective of helping investors achieve their respective goals, while appreciating that delegation involves hiring agents who may/not be skillful, and have them operate within restricted relative risk budgets. We must approach this challenge with the view that "investors delegate to maximize risk-adjusted relative returns," as this is how investors behave in reality (as opposed to a simplifying academic construct). Finally, with respect to investing, it must be acknowledged that, "it's all relative." As Albert Einstein noted, "The world as we have created it is a process of our thinking. It cannot be changed without changing our thinking."[29]

Notes

[1] https://www.brainyquote.com/topics/wealth.

[2] Or as Levy and Markowitz (1979) show, an investor with a particular single period utility function could achieve almost maximum expected utility if they acted only on the basis of expected return and variance.

[3] In alphabetical order, Lintner (1965), Mossin (1966), Sharpe (1964), and Treynor (1966).

[4] Though many also consider the Treynor ratio.

[5] M-square expresses risk-adjusted performance in return terms (as opposed to a ratio as in the Sharpe ratio) and is established by levering/delevering the portfolio under consideration, using the risk-free asset to achieve the same volatility of the "market" portfolio. M-square is preferred to the Sharpe ratio as it is expressed in return terms and provides useful asset allocation advice. See also Graham and Harvey (1994).

[6] In this approach, the utility function is implicit.

[7] Over a 25-year career, the author has managed a multinational pension fund as well as worked with pension funds in Australia, Canada, Japan, the Netherlands, and the United States.

[8] Muralidhar (2018).

[9] Novy-Marx and Rauh (2009).

[10] For example, discounting stochastic liabilities with a "risk-free" rate—again, back to the key point of using an absolute wealth approach to a relative wealth challenge.

[11] https://www.pionline.com/article/20181120/ONLINE/181129996/local-805-teamsters-cleared-for-benefit-reductions-ibew-local-237-applies.

[12] Caused by demographic changes, low funding, generous benefits and low productivity growth.

[13] https://www.barrons.com/articles/as-robo-advisors-cross-200-billion-in-assets-schwab-leads-in-performance-1517509393.

[14] The author was briefly an advisor to a robo-advisor and has had meeting with other robo vendors.

[15] A bond that would perfectly replicate the typical retirement cash flows is very different from any currently available liquid/tradeable financial product or instrument (unless heavily financially engineered).

[16] Prof. Sharpe has acknowledged the importance of liabilities in asset pricing in private correspondence.

[17] In the Zero-Beta CAPM, the "risk-free" asset has non-zero volatility. Waring and Whitney (2009) argue that the Liability-replicating portfolio is the "risk-free" asset because it has non-zero volatility, and hence would allocate assets between the hedging portfolio and the "risky" market portfolio. However, this requires a big caveat that the liability-replicating portfolio has zero beta to the market portfolio.

[18] MOS explains that the "relative market portfolio" is the set of all assets excluding the liability-replicating asset and including the traditional risk-free asset.

[19] http://www.nmpera.org/assets/uploads/downloads/RIO/RFP/RFP-NO.-NM-INV-001-FY19-Total-Fund-Overlay-Services.pdf.

[20] And more importantly that the "relative market portfolio" should exclude the benchmark and include the absolute risk-free asset—a point noted in MOS.

[21] Muralidhar (2000) extends M-square by examining the risk-adjusted portfolio created by combinations of the benchmark, traditional risk-free asset, and the risky portfolio, subject to the volatility of this combination equal to the volatility of the benchmark, and the tracking error of this combination portfolio equal to a target value. They demonstrate why this measure is applicable for delegation, especially since it is the only measure that ranks delegated portfolios identical to rankings based on the confidence in the skill of agents.

[22] By close to a factor of 10.

[23] https://www.lacera.com/Opportunities/RFP/cash_overlay_manager/rfp_cash_overlay_manager.pdf, page 12.

[24] Prof. Robert C. Merton has noted that if everyone has a different relative risk-free asset, then this approach would probably only get more complicated if we assume that the model must incorporate multiple goals, in addition to retirement.

[25] Muralidhar (2017) attempts to derive an asset-pricing model using the M-cube performance measures and multiple goals, but does not show the utility function that corresponds to this approach.

[26] Merton (2007) had noted that regulations for corporate pension funds had led to a mispricing of risk, which were hidden as stock markets rose but revealed clearly after the 2000–2002 crash in equities.

[27] https://www.ai-cio.com/news/dutch-pensions-felt-major-pain-q4/.

[28] A similar case can be made for saving for a child's college—the safe bond is one issued by colleges and universities that pays for just four years, real cash flows linked to tuition inflation (Muralidhar, 2016). However, innovation will be needed to find a way to help those saving for future health costs as there is no simple way to hedge future health expenses with a simple "risk-free" asset.

[29] https://www.goodreads.com/author/quotes/9810.Albert_Einstein.

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