RETIREMENT MANAGEMENT JOURNAL

A reprinted article from Volume 8, Number 1, 2019

MANAGING LONGEVITY RISK

The Case for Longevity-Indexed Variable Expiration Bonds

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INVESTMENTS & WEALTH INSTITUTE®
formerly IMCA

VOLUME 8
NUMBER 1
2019

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ABSTRACT

There is an annuity puzzle in that the actual allocation by individuals to annuities is low. Longevity bonds, to hedge overall economy-wide mortality risk, have been proposed, but these bonds have challenges and the proponents have not shown how governments are hedged. This paper recommends that governments should create Longevity-Indexed Variable Expiration (LIVE) bonds instead. These cohort-specific bonds, targeted to individuals (and institutions) would pay income only, and they would start paying only after the average life expectancy of that cohort. Payments will be based on tax collections of that cohort, ensuring the government is fully hedged, and therefore a natural, low credit risk, issuer. Another innovation covers the life expectancy of those whose lives are shorter than the average, so only those individuals who live beyond the average (usually wealthier portions of the population) and with high risk of outliving their resources need to purchase LIVE bonds. LIVE bonds benefit individuals who want a low-cost and liquid longevity hedge with the ability to bequeath balances on death. This paper also briefly discusses the portfolio strategies of those living beyond average life expectancy and how governments can ensure that they have sufficient funds to bear this risk.

It is a well-known fact that annuity contracts, other than in the form of group insurance through pension systems, are extremely rare. —Franco Modigliani, PhD (1986)

BACKGROUND

Thirty years after Franco Modigliani noted in his Nobel speech that annuities are underutilized (the "annuity puzzle"), the problem appears to persist with little progress. Salisbury and Nenkov (2016) note, "In June 2015, U.S. retirement assets totaled $24.8 trillion, with only 8.6% of assets held as annuity reserves."[1] Many explanations have been offered for this annuity puzzle including adverse selection (i.e., only those who know they will live long want to buy annuities), bequest motive (Lockwood 2012), complexity/inflexibility of contracts (Mitchell et al. 2000), and mortality salience (Salisbury and Nenkov 2016). Beshears et al. (2013), using survey data, note that even when the annuity option is the default in defined benefit (DB) schemes, people opt for the lump-sum option because

These cohort-specific bonds, targeted to individuals (and institutions) would pay income only, and they would start paying only after the average life expectancy of that cohort.

although they want lifetime income, they want flexibility in their spending and they also worry about the credit risk of the plan sponsor.[2]

Two approaches to this challenge have been to focus on helping insurance companies lower costs and risks and to try to educate customers about the value of such instruments—both with little success. To address the former, Blake and Burrows (2001) have recommended that governments issue "survivor bonds" or "longevity bonds":

> *These are financial products whose coupon payments are linked to the aggregate mortality experience of a specified cohort of individuals. By making such bonds available to the private sector, annuity providers would be able to hedge their exposure to aggregate mortality risk.*

With respect to the efficacy of the latter, Thaler (2013), writing about financial literacy programs, states:

> *A new paper by three business school professors … presents a discouraging assessment of attempts to teach people how to deal with money. … over all, financial education is laudable, but not particularly helpful. Those who receive it do not perform noticeably better when it comes to saving more, for example, or avoiding ruinous debt. Even more depressing, the results of efforts aimed at low-income people are particularly weak. Those who need the help most seem to benefit the least.*

This paper attempts to provide an alternative solution—it is focused instead on helping individuals address the challenge

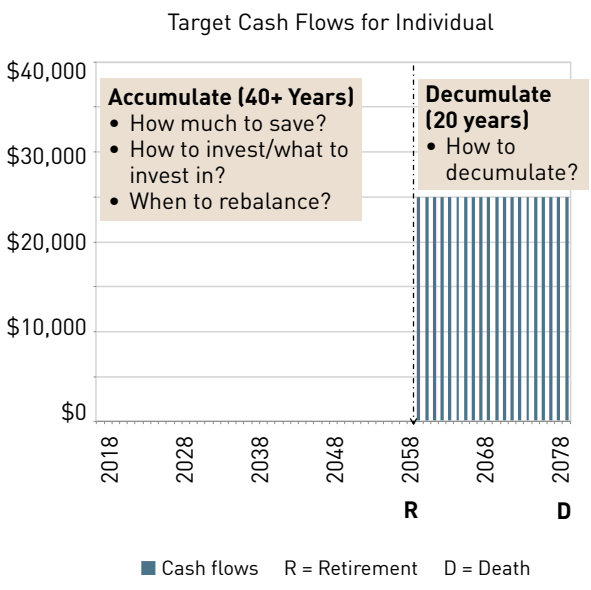
of managing longevity risk, though the proposed innovation also could be used by institutions to improve their product offering. This paper suggests that governments should create longevity-indexed variable expiration (LIVE) bonds. These bonds would pay income only, and start paying only after the average life expectancy of the society (because retirement income through life expectancy will have been addressed with a complementary BFFS/SeLFIES bond).[3] Each bond will be cohort-specific and based on tax collections of that cohort, with a coupon structure that partially leverages the Blake and Burrows (2001) approach. In this fashion, the government is fully hedged (because the bond will be a form of a collateralized debt obligation or CDO), and therefore a natural issuer, with low credit risk. Because BFFS/SeLFIES cover the life expectancy of those whose lives are shorter than the average, only those individuals who live beyond the average (usually wealthy portions of the population), who do not receive a sufficient DB pension,[4] and with high risk of outliving limited resources need purchase LIVE bonds. These facets make it easier for governments to issue such bonds.

THE RETIREMENT PLANNING CHALLENGE

Investors, especially in defined contribution (DC) plans, seek to ensure a guaranteed, real income from retirement through death much like they would receive from a DB plan. This is shown in figure 1, which captures the perspective of a twenty-five-year-old and where "R" marks the date of retirement at age sixty-five, and retirement is assumed to last twenty years (and death is marked by the "D"). This simple example assumes that investors know they will all die in twenty years (the approximate average life expectancy of the United States, at age sixty-five). Additionally, assume the investor seeks $25,000 annually in real retirement income from private savings or from a DC plan (with the balance derived from Social Security or an employer DB). It is also reasonable to assume the investor would want to lead a lifestyle comparable to pre-retirement. This goal may appear extremely simple, but achieving it in practice is extremely hard for a number of reasons.

Figure 1

SAVING FOR RETIREMENT THAT STARTS AT AGE 65 AND LASTS 20 YEARS, INDEXED TO A COST-OF-LIVING INDEX



Planning for retirement is a complex mix of three basic questions: (1) how much to save; (2) how to invest—further separated into: which assets to hold, how much of each to hold, and how to rebalance; and (3) how to withdraw so as to not deplete the asset pool too early. Complicating retirement planning is the fact that a majority of individuals globally lack basic skills needed for this sort of planning. They are unable to answer basic questions about compounding, inflation, and diversification (Klapper et al. 2015). To add to these challenges, finance theory has some gaping holes in helping individuals develop a robust approach to this problem (Muralidhar 2017, 2019). More chronically, the financial instruments available in the market today either do not offer an easy way to hedge the cash-flow profile in figure 1, or if they are available, they tend to be complex, costly, risky, and illiquid. For example, one could argue that a deferred life annuity (or even a Treasury Inflation-Protected Securities ladder) would offer such a profile, but with costs in some cases approaching 2 percent per annum (p.a.) to provide this hedge, it is no surprise there is an annuity puzzle. Moreover, Social Security offers a hedge against longevity but there are many limitations to sourcing this longevity hedge. Appendix A shows the difference between Social Security and the proposed innovation for hedging longevity risk.

Investing in existing assets (stocks, bonds, real estate investment trusts, or even target-date funds) is risky relative to this objective, because these assets do not provide a simple or low-cost cash flow hedge against desired retirement income (Merton 2012; Kobor and Muralidhar 2018). An annuity would appear to be an option to consider. Annuity providers worry about adverse selection (i.e., only those who feel they will live long will buy these instruments) and they struggle to hedge aggregate mortality risk even if they are able to pool many individuals plus they must earn a profit for putting shareholders' capital at risk. Thus, they tend to make contracts complex, costly, and illiquid. Further, individuals still have some credit risk that the insurance provider goes bankrupt before these payments come due and, in some cases, cannot leave a bequest to heirs if they die early.

In short, one can distill the individual's retirement problem into wanting to ensure sufficient retirement income (or how much) until death (or how long). For simplicity, we address the two separately in this paper.

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A SIMPLE WAY TO ADDRESS 'HOW MUCH' (FOR A FIXED TERM)

Muralidhar et al. (2016) recommend the creation of BFFS. By recognizing that retirement investing is entirely about cash flows, Muralidhar et al. (2016) sought to create a new instrument that generated appropriate cash flows to meet the retirement goal. Merton and Muralidhar (2017a, b) extend BFFS and advocate a specific inflation-indexation to create SeLFIES because standard-of-living risk and not inflation is one of the biggest risks in retirement.

BFFS/SeLFIES bonds would start paying investors upon retirement, and pay a fixed $5/year real income for a period equal to the average life expectancy at retirement (e.g., U.S. bonds would pay for say twenty years).[5] They incorporate two key innovations: (1) the retiree's desired annuity-like cash-flow profile in the payout phase as in figure 1, thereby blending accumulation and decumulation into one instrument, and (2) indexing BFFS/SeLFIES to per-capita consumption. The case for BFFS/SeLFIES was predicated on the fact that rather than creating new bonds with longer maturities than currently available, governments should issue bonds that are the safe instrument for even a twenty-five-year-old planning for retirement (by pushing the forward start date of cash flows to as much as forty years). This simple instrument would democratize access to fair, low-cost, and transparent retirement planning even for the most financially unsophisticated investor (Muralidhar 2019).

In addition, BFFS/SeLFIES can be bequeathed to heirs (much like in Brown 2014), unlike sometimes high-cost, inflexible, and illiquid annuities.

Merton and Muralidhar (2017a, b) state:

> *SeLFIES are a good deal for governments, too. In fact, governments are the biggest beneficiaries. First, cash flows from SeLFIES reflect synergistic cash flows for infrastructure spending, namely, large cash flows upfront for capital expenditure, followed by delayed, inflation-indexed revenues, once projects are online. Second, SeLFIES give governments a natural hedge of revenues against the bonds, through value-added taxes.*

One could make a case that insurance companies also could be issuers of these bonds because these bond cash flows are similar to the cash flows of fixed-term annuities.

LONGEVITY RISK AND LONGEVITY BONDS

Clearly, the biggest drawback to BFFS/SeLFIES is that they do not hedge longevity risk for the individual because they stop paying after twenty years (or some other fixed term linked to average life expectancy). Merton and Muralidhar (2019) go a step further and suggest that SeLFIES do not directly provide an embedded annuity feature of payments for life but do contribute to longevity risk protection for those who eventually select full or partial annuitization at retirement and provide decision flexibility to those who do not want to annuitize. Under certain conditions, the retiree can simply exchange SeLFIES for a life annuity with no extra payment and no reduction of retirement income level.[6]

If insurance companies cannot effectively hedge that risk, they have to charge customers for this risk, which still raises the cost of annuities. Moreover, it still maintains the product that individuals consider complex, unfair, and illiquid.

Alternatives include creating ladders of BFFS/SeLFIES bonds (Muralidhar et al. 2016)—i.e., buying bonds that start later and mature later, or purchasing deferred life annuities (i.e., that start paying when the individual is eighty-five), which are likely to be relatively less expensive than current annuities (Brown 2014; Merton and Muralidhar 2017b). However, the latter approach still leaves the challenge that insurance companies will need to bear longevity risk of the pool. If insurance companies cannot effectively hedge that risk, they have to charge customers for this risk, which still raises the cost of annuities. Moreover, it still maintains the product that individuals consider complex, unfair, and illiquid.

Blake and Burrows (2001), Blake et al. (2006), Blake et al. (2014), and Tan et al. (2015) seek to address this issue and suggest the issuance of "longevity bonds" by governments specifically for this purpose. Alternatively, Merton and Muralidhar (2019) demonstrate how SeLFIES might be used to hedge aggregate longevity risk. The key features of the longevity bond are as follows:

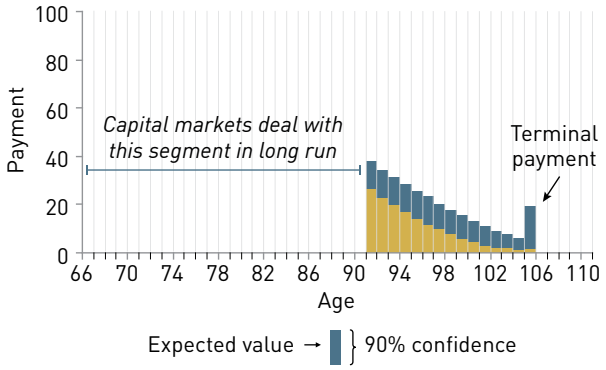
1. The bond pays coupons that decline over time in line with the actual mortality experience of a cohort of the population.
2. Coupon payments are not made for ages for which longevity risk is low.
3. The coupon payments continue until the maturity date of the bond, which might, for example, be forty years after the issue date when the cohort of males reaches age 105.
4. The final coupon incorporates a terminal payment equal to the discounted value of the sum of the post-105 survivor rates to account for those who survive beyond age 105.
5. The bond pays coupons only and has no principal repayment. It is designed to hedge systematic (also known as aggregate or trend) longevity risk.

The cash flows of these longevity bonds are shown in figure 2, which assumes that these bonds start paying at age ninety until age 105.[7] The choice of a declining payment every year is critical to the success of this bond, as will be shown in the section below, LIVE Bonds. These bonds are targeted to insurance companies and the goal of this approach is to suggest that the annuity puzzle can be addressed by lowering the cost of creating these annuities. However, it is not clear how the government is hedged in the issuance of these bonds.

Figure 2

DEFERRED TAIL LONGEVITY BOND FOR MALE AGE 65

Longevity bond payable from age 90 with terminal payment at age 105 to cover post-105 longevity risk



Source: Blake et al. (2014)

There is a danger that the cost of hedging this risk is transferred to future generations because governments tend to look after current generations at the cost of future generations. Blake et al. (2014) recognizes an additional challenge that can be termed "basis risk." Their bond offering is not cohort-specific—it is set at a national level and as they note, "Different birth cohorts have different survivor rates to each age." Further, as they also note, "yet another reason for basis risk involves the difference between 'lives' and 'amounts.'"

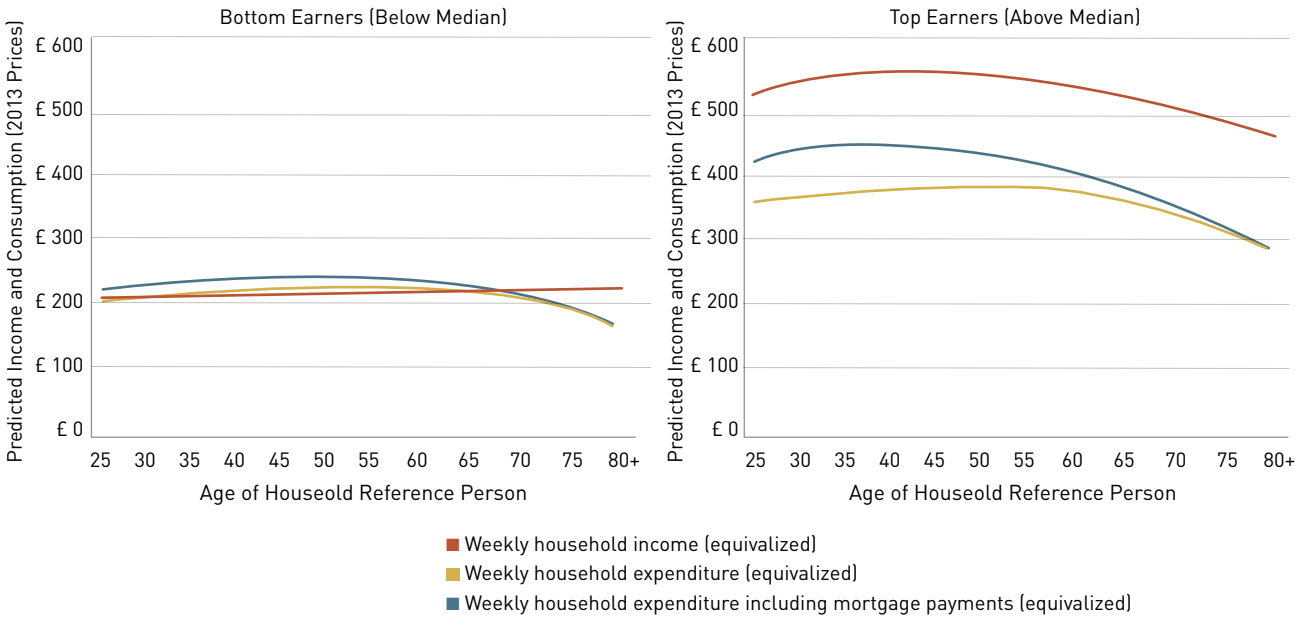
LIVE BONDS

Unlike the longevity bonds, SeLFIES/LIVE bonds are targeted to individuals, but they also could be used by institutions to create better products. We start by assuming that Social Security's longevity hedge is limited as noted in appendix A and BFFS/SeLFIES exist. We also assume that one's consumption post retirement is adequately represented by figure 3, which can be assumed to be relatively flat through retirement with a slight tapering off as individuals age as shown by the declining lines marked "weekly household expenditure." Ebrahimi (2019) further validates figure 3 and notes, "average annual spending declined as households aged." Interestingly, the age sixty-five to seventy-four cohort spent 22 percent less than the fifty-five to sixty-four cohort, and the age seventy-five and older cohort spent 23 percent less than the sixty-five to seventy-four cohort.

LIVE bonds are cohort-specific, pay amounts that are fairly clearly articulated (and similar in concept to longevity bonds), and seek to hedge individual longevity risk as opposed to

Figure 3

PEOPLE SPEND PROGRESSIVELY LESS AS THEY AGE



Source: Brancati et al. (2015)

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society-wide longevity risk. The issues with annuities (such as adverse selection and aggregate mortality risk) are solved by the combined innovations of BFFS/SeLFIES and LIVE bonds. A typical bond has three features that can be tweaked to create the "ideal" bond: (1) the coupon—both what is paid and when it is paid, (2) the number of bonds outstanding, and (3) the maturity. Because we want a bond to cover longevity risk, the maturity will need to be flexible, in which case either the coupon or the number of bonds will need to decline over time. For this iteration of LIVE, we assume that the adjustment takes place in the coupon. We address why reducing the number of bonds is difficult in the section below, Challenges with LIVE Bonds and Some Extensions.

We start by recognizing that in a country, an average life expectancy of say twenty years at age sixty-five assumes that at least 50 percent of the population will live less than the average and 50 percent will live longer than the average. The material issue is: Who lives below the average and who lives above the average? Muralidhar (2018) shows that poor and minority populations typically are shorter-lived (i.e., less than the average), and therefore they are covered by BFFS/SeLFIES (on average). The setting of the maturity of the BFFS/SeLFIES bond to the average life expectancy was done intentionally to ensure that poor/minority populations are protected (and they do not end up subsidizing rich/majority populations in cases where there is mandatory annuitization as in DB plans or collective DC plans).[8] Moreover, because these bonds can be bequeathed to heirs, shorter-lived population sub-groups can have longevity risk protection and have some bequests, thereby overcoming the challenges inherent in annuities.

But this leaves open the question of how longer-lived citizens are hedged, and this is the focus of the LIVE bond. On average, higher-income individuals tend to have longer life expectancy. Not all those who live longer than the average need longevity risk insurance (because some may be sufficiently wealthy to not have to deal with the concern of outliving their wealth). Further, some long-lived individuals may be receiving sufficiently large DB pension benefits that give them a replacement rate in retirement in excess of the typical 70 percent of final/average income recommended in Aon (2008). Therefore, the demand (and in turn supply needs) for LIVE bonds is limited (i.e., does not need to cover the entire 50 percent who survive beyond age eighty-five). This is an important issue because it makes these bonds simple to create and implement (without creating burdens on other cohorts, thereby leading to intergenerational subsidization). We consider two versions of the bond—a complex (more complete version) and a much simpler version.

THE COMPLEX, COMPLETE VERSION

The key features of complex but more complete LIVE bonds include the following:

- The bond is issued for the year of birth so there is one bond for every year or cohort—it is clearly cohort-specific. Each individual seeking to hedge longevity risk would buy the bond of their year of birth.
- The bond will pay real coupons only (like longevity bonds, BFFS/SeLFIES) and these coupons are financed by cohort tax revenue as discussed below.
- The bond will start paying only after age eighty-five for that cohort. The 1960 LIVE bond will only start paying after 2045 on the assumption that BFFS/SeLFIES can be used for the period 2025–2045.
- Each bond will pay a specific real dollar amount that is equal to the percentage of the population alive at age eighty-five multiplied by the percentage of the surviving population that needs coverage.
  - » For example, if 50 percent survive beyond age eighty-five and just 50 percent of the surviving population needs to be covered, then the first coupon will be $25.
  - » If, for simplicity, in the first year, 2.5 percent of the cohort dies (i.e., 47.5 percent survives), then the second coupon will be equal to $23.75 or half of 47.5 percent and so on.
  - » Figure 4 provides a simple example of how the bond payments would decline on the basis of 2.5 percent passing away every year (and only 50 percent of the survivors need to be covered), and assumes a population with just 100 people. Notice that the declining coupon may be a potential match for the declining expenditure shown in figure 3. Table 1, column 2, provides the data to support this analysis and ignores inflation-indexation to keep the analysis simple and in real terms.
- If an individual dies at any time post age eighty-five, the expectation is that the individual's heirs liquidate their LIVE bond position because there is no need for the hedge anymore.

Figure 4

PERSPECTIVE OF THE LONGEST-LIVED MEMBER OF THE COHORT

Cash Flows, Target Holding, and Total Number of Bonds Issued

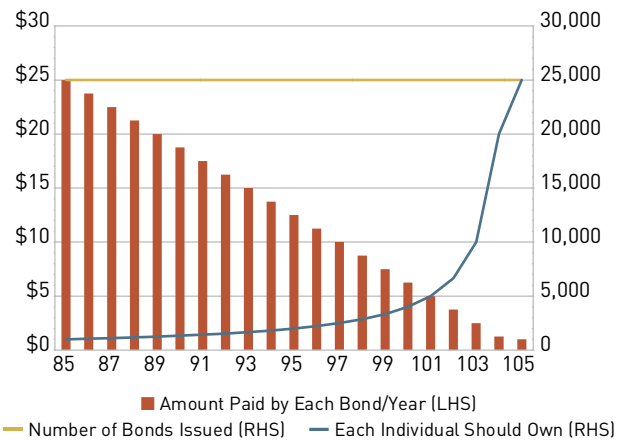

Table 1

PERSPECTIVE OF THE LONGEST-LIVED MEMBER OF THE COHORT: AGE, REAL BOND COUPONS, TARGET HOLDING, AND TOTAL REAL INCOME EARNED IF TARGET HELD

Cohort Age	Amount Paid by Each Bond/Year	Number of Bonds Issued	Amount Each Individual Should Own	Amount Earned by Each Individual If Holding the Correct Amount of Bonds vs. Target Income
(1)	(2)	(3)	(4)	(5)
85	$25.00	25,005	1,000	$25,005
86	$23.75	25,005	1,053	$25,005
87	$22.50	25,005	1,111	$25,005
88	$21.25	25,005	1,177	$25,005
89	$20.00	25,005	1,250	$25,005
90	$18.75	25,005	1,334	$25,005
91	$17.50	25,005	1,429	$25,005
92	$16.25	25,005	1,539	$25,005
93	$15.00	25,005	1,667	$25,005
94	$13.75	25,005	1,819	$25,005
95	$12.50	25,005	2,000	$25,005
96	$11.25	25,005	2,223	$25,005
97	$10.00	25,005	2,500	$25,005
98	$ 8.75	25,005	2,858	$25,005
99	$ 7.50	25,005	3,334	$25,005
100	$ 6.25	25,005	4,001	$25,005
101	$ 5.00	25,005	5,001	$25,005
102	$ 3.75	25,005	6,668	$25,005
103	$ 2.50	25,005	10,002	$25,005
104	$ 1.25	25,005	20,004	$25,005
105	$ 1.00	25,005	25,005	$25,005

- If an investor survives one year beyond 2045, the investor would increase the LIVE bond holding according to a specific formula (essentially purchasing the bonds that heirs of deceased cohort members sell). This additional allocation is needed to maintain the target income if fixed because each bond pays a reduced amount every year. An investor may not need to do anything if expenditure declines as in figure 3. A fixed target income post average life expectancy also raises a challenge because individuals will need to keep aside resources to make these additional purchases—not an easy thing to do. With each death in a cohort, the cohort's tax revenue declines for future years, and the LIVE bond pays coupons on a declining scale. Table 1, column 4, demonstrates how the LIVE bond allocation has to be scaled up every year depending on the number of people who survive each year if one seeks a fixed target retirement income. A similar analysis can be conducted for declining target retirement income shown in figure 3, which may require fewer rebalancings.
  - The target holding for any year equals the target income divided by the dollar coupon paid in that year.
  - The other alternative to this approach would be to purchase a strip of call options that guarantee the same income in all years (i.e., to buy the additional bonds based on today's pricing forward curve). If the individual survives, the individual exercises the option and receives the income; if the individual dies, the heirs can either exercise the options if they are in the money (or sell them to others) or allow them to expire worthless if they are out of the money. The benefit to this approach is that the cost of the basket of options is known on day 1 and therefore there is no uncertainty about future coverage (but some of the options could expire worthless).

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- The amount to be financed by the government and the number of total bonds issued will be established through the following process:
  - » The government sets a target retirement income, post age eighty-five, that the LIVE bond seeks to guarantee (e.g., according to the 2015 Internal Revenue Service (IRS) tables, the average (total) income of the "65 and Over" cohort is $77,246. Assume that the government wants to replace 32.4 percent of this income until death. Therefore, the target average income for this cohort is approximately $25,005; 32.4 percent was chosen to create a value approximating $25,000.
  - » The amount to be financed by the government equals the target income multiplied by the number of members of the cohort to be financed.
  - » Number of bonds to be issued equals the amount to be financed in year 1 divided by the first coupon. Table 1, column 3 shows that this number is 25,005 assuming 100 citizens and a target average retirement income of $25,005.
- The tax revenue against which the bond pays is equal to all the tax revenue of the cohort, and will be forecasted ahead of time using historical data that the tax authorities already have readily available.
- Whether the cohort's revenue is sufficient to pay for the bond will depend on a relatively simple equation provided below in the section below, How LIVE Bonds Would Work for Governments.
- As the cohort dies off, the revenue keeps declining until the final member of the cohort dies. To ensure that the final participant has sufficient income from holding 100 percent of the cohort's LIVE bonds, some part of the cohort's previous tax revenue could be set aside to ensure sufficiently large payments as discussed in the section below, How LIVE Bonds Would Work for Governments.
- In this fashion, LIVE bonds address the "how much" and "how long" questions for those who survive beyond age eighty-five. The coupon payments and portfolio allocations are a bit more complex than under BFFS/SeLFIES, but this is required if retirees want a fixed target retirement income (as opposed to a declining desired retirement income as in figure 3) because the cohort-tax revenue also is declining as each member dies.

In effect, one can summarize the key aspects of LIVE bonds as follows[9]:

1. If the entire tax proceeds are used to pay the LIVE bond holders, then the total coupons to be paid each year are the tax rate multiplied by the income of the cohort (depending on how many require such a hedge as noted below).
2. In effect, the coupons represent a transfer from all members of the cohort to bond holders (and the price of this transfer is the price of a bond).
3. Each year, the taxed fraction of the cohort's income is shared with the bond holders in proportion to their shares in bond holdings.
4. The price of the bonds will decline over time to reflect approaching maturity and the declining coupon (unless there is an unusual demand for these bonds by speculators for some currently unforeseen reason).

Interestingly, we can price this version of the LIVE bond given the projected cash flows of the bond in table 1, column 2, and using the traditional bond pricing curve of these future cash flows. The current price of this bond (using October 2018's real yield curve), assuming an individual turns sixty-five on January 1, 2019, and the LIVE bond starts paying January 1, 2039 (for total cash flows of $264), would be approximately $190. Clearly, there are challenges with this price because we are extrapolating the curve beyond rates that currently exist. In addition, to the extent that cash flows differ because of the difference in actual mortality rates relative to what was expected, the price will vary. Ultimately, the price will be determined by demand and supply forces around this approximate price. However, this idea of a longevity-indexed instrument, with an expiration (or maturity) that depends on longevity, validates the usefulness and name of the bond.

THE SIMPLER, INCOMPLETE VERSION

The simpler version would be along the lines of SeLFIES. We know that, for example, from the U.S. Social Security's 2015 Life Tables the U.S. longevity at age eighty-five for males is 5.87 years and for women is 6.91 years (and at ninety years of age it is 4.03 and 4.67 years, respectively).[10] So, the simple version of the LIVE bond would be to issue a LIVE bond that has all the features of BFFS/SeLFIES—namely, that they start paying individuals when they hit age eighty-five, pay the same $5 real income, and pay for a period equal to say ten to fifteen years (i.e., covering individuals from age eighty-five to ninety-five for the ten-year bond or from eighty-five to 100 for the fifteen-year bond). The nice thing about this version is that there are no additional portfolio rebalancing strategies; the individual is guaranteed real income for ten years from age eighty-five to ninety-five and now bears some risk of outliving the final maturity of these bonds. One could argue, however, that this is likely to be borne by a small fraction of the population; therefore, the simplicity of this version might dictate the choice of this approach. Interestingly, a fifty-five-year-old on October 2018, who would like to guarantee getting paid $5 real income from age eighty-five to ninety-five, would have to pay $32 for a LIVE bond based on the October 2018 Treasury Inflation-Protected Securities curve. By comparison, the SeLFIES that would pay them $5 real income from ages sixty-five to eighty-five would cost $79. Recall, that this version of the LIVE bond is much like the 2048 SeLFIES, but for just half the coupon period (so alternatively, the financial markets can strip out the coupons from the 2048 SeLFIES for the desired longevity hedge for the person who turns eighty-five in 2048).

THE BENEFIT TO INDIVIDUALS

LIVE bonds offer individuals a liquid, low-cost, and potentially simpler way to hedge longevity risk (and declining consumption) compared to current annuities. Many analysts have recommended that everybody should be forced to participate in a collective DC plan so that longevity risks are pooled across entire populations; however, this approach leads to a "Robin Hood in reverse" problem because the poor and minority populations, with lower than average life expectancy, subsidize the rich and majority populations. LIVE bonds, on the other hand, offer choice as opposed to a mandate to hedge longevity risk and they offer a transparent market price for such a hedge. LIVE bonds also allow individuals to easily hedge a desired target retirement income level and potentially even change that desired level by changing the number of bonds they hold. While not as simple as BFFS/SeLFIES and therefore not entirely understandable to those not financially sophisticated, LIVE bonds potentially allow insurance companies to better hedge their annuities and could lead to lowering the cost and complexity of these products. Finally, one option could be to allow investors to pick an "income reinvestment plan" such that if they have resources to cover retirement consumption, then the income earned from the bond automatically is used to buy more LIVE bonds (allowing for the adoption of good behavioral finance).[11]

HOW LIVE BONDS WOULD WORK FOR GOVERNMENTS

Governments around the world are starting to realize that there is a looming retirement crisis, especially among DC plans, and that there is a critical need to improve and foster better retirement income options (U.S. Treasury 2017; Australian Treasury 2018). One could make the argument that Modigliani and Muralidhar (2004), Blake and Burrows (2001), or even Merton and Muralidhar (2017a) do, that governments need to step in. They need to complete markets and ensure good retirement outcomes; otherwise, if many individuals retire poor, the government will end up bearing the cost or the societal consequences. Therefore, they need to be at the frontier of these innovations to ward off retirement poverty and longevity risk.

Why might this idea of a LIVE bond work for governments? Collateralized revenue obligations (CROs), where the coupon is tied to the revenue of a cohort that the tax authority tracks (in the United States, the Internal Revenue Service) allows the government to be fully hedged and there are no intergenerational transfers to hedge the longevity risk of a single cohort. The complex LIVE bonds would be much like a CDO, a collateralized loan obligation (CLO), or an asset-backed security (ABS)—so the type of instrument exists; LIVE just changes the basis of the coupon (not creating an entirely new instrument such as the longevity bond). The crux of the complex LIVE bond is that tax revenues of cohorts will depend on life expectancy (and income levels). To the extent retirees have inflation-indexed (or standard-of-living-indexed) retirement income, taxes on this income also are inflation-linked and allow the government to afford an inflation hedge. Because the bond is tied to cohort tax revenue, the government is monetizing its future revenues with bond receipts today and helping create or complete the markets for these hedges where annuities have failed. By collateralizing the coupon payments to a specific revenue stream, the government is hedged and the investor is protected from political risk. This is just good asset-liability management for the government.

Therefore, we demonstrate the impact of various parameters of a complex LIVE bond on government finances; we ignore the simple LIVE bond because it is relatively trivial. The assumptions for this study are provided in appendix B, and the simple model is as below.

Define the following variables:

a_t = age of cohort at time t, where

$$a_{t+1} = a_t + 1 \quad (1)$$

p_t = percentage of population alive at time t;

$$p_t = 100\% \text{ when } a_t \leq 65,\ p_{t+1} = p_t - 2.5, \text{ when } a_t > 65 \quad (2)$$

P_t = Actual population alive at time t (proxied by number of individuals filing tax returns and accounting for joint returns)

For simplicity, we assume an economy with just 100 citizens, so now the percentage and number alive are the same.

$TAGI_t$ = Total Adjusted Gross Income of a Cohort at time t

$$CAY_t = \text{Cohort Average Income at } t = TAGI_t / P_t \quad (3)$$

τ = average tax rate—which we will assume to be approximately 15 percent (see appendix B).

$$CTR_t = \text{Cohort Tax Revenue at time } t = \tau \times TAGI_t = \tau \times CAY_t \times P_t \quad (4)$$

pc_t = percentage of population to cover post age eighty-five, assumed to be 50 percent.

$rpr_{\%}$ = replacement rate of average cohort income to cover after age eighty-five, assumed to be between 20 percent and 30 percent.

$$RPR_{\$,t} = \text{dollar income value of target replacement rate at time } t = rpr_{\%} \times CAYt \quad (5)$$

$$CYF_t = \text{Cohort Income to be Financed at time } t = pc_t \times P_t \times RPR_{\$,t} = pc_t \times rpr_{\%} \times P_t \times CAYt \quad (6)$$

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CYF_t is in effect the total size of the bond issue for each cohort, and each member of the cohort buys the desired share of this bond issue to ensure that they get paid until their death. If they plan well, every member of the cohort can achieve the target replacement rate of the average cohort income.

Very simply, for good asset–liability management, the government needs to ensure that the following basic conditions hold:

1. If $CTR_t > CYF_t$ (i.e., very few require longevity risk insurance), then the government can use current revenues of the cohort to ensure longevity risk is managed at a sufficient income level.
2. If $CTR_t < CYF_t$ (i.e., many desire longevity risk insurance relative to income the government will earn from current revenues), then the government will need to create a reserve fund, well before the cohort reaches average life expectancy, using previous revenues of the cohort (e.g., tax revenue from the cohort from ages sixty-five to eighty-five). The reserve fund will be used to ensure longevity risk is managed at a sufficient income level.

Note that whether CTR_t is greater than or less than CYF_t depends simply on whether τ is greater than or less than or equal to $pc_t \times rpr_{\%}$. We now show these three cases:

Case 1: $\tau = 15\%$, $pc_t = 50\%$ and $rpr_{\%} = 30\%$. $CTR_t = CYF_t$

As figure 5 shows, the amount to be financed is exactly equal to the revenues earned from this cohort and the government is easily hedged. This also is shown in table 2 (column 8 shows a zero deficit). This follows because $\tau = pc_t \times rpr_{\%} = 15\%$.

Case 2: $\tau = 15\%$, $pc_t = 50\%$ and $rpr_{\%} = 25\%$. $CTR_t > CYF_t$

As figure 6 shows, the amount to be financed is less than the amount earned by the government and the government is easily hedged. In other words, $\tau > pc_t \times rpr_{\%}$ or $15\% > 12.5\%$.

Case 3: $\tau = 15\%$, $pc_t = 70\%$ and $rpr_{\%} = 30\%$. $CTR_t < CYF_t$

As figure 7 shows, the amount to be financed is greater than the amount earned by the government from current revenues from the cohort (i.e., from age eighty-five onward); therefore, the government will need to create the reserve fund from some of the cohort's revenues pre age eighty-five. Again, $\tau < pc_t \times rpr_{\%}$ as $15\% < 21\%$.

CHALLENGES WITH LIVE BONDS AND SOME EXTENSIONS

It may seem obvious that governments should and could innovate to improve retirement security, but change comes slowly to governments. In fairness, the examples provided in this paper were kept simple. They are meant to make the case and

Figure 5

COHORT TAX REVENUE EQUAL TO COHORT INCOME TO BE FINANCED POST AGE 85

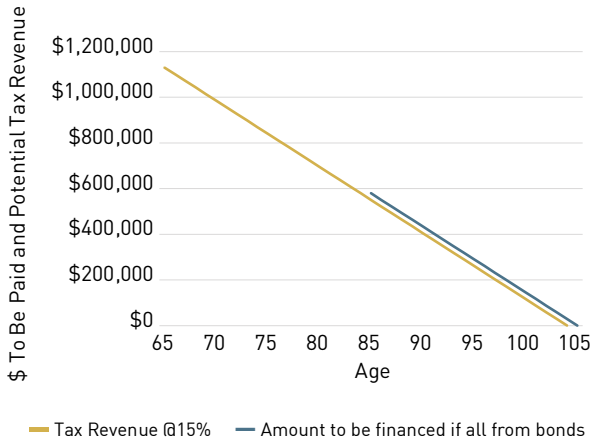


Figure 6

COHORT TAX REVENUE GREATER THAN COHORT INCOME TO BE FINANCED POST AGE 85

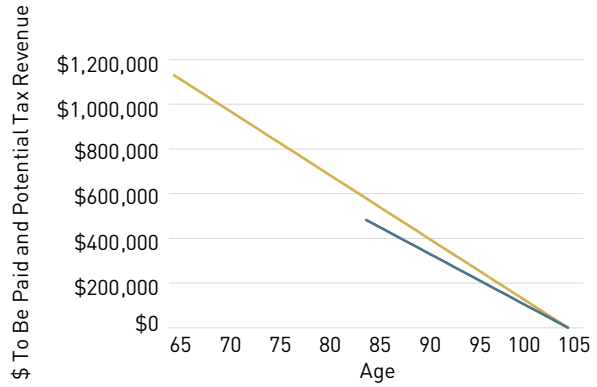
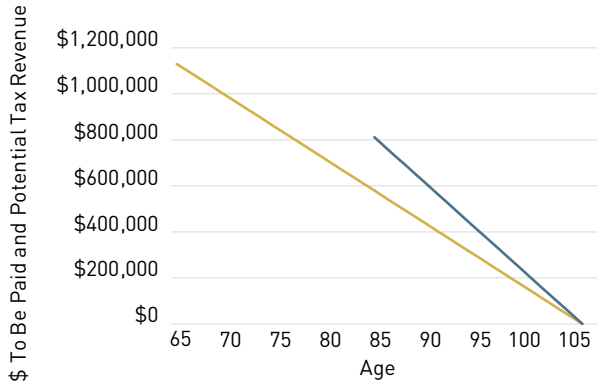


Figure 7

COHORT TAX REVENUE LESS THAN COHORT INCOME TO BE FINANCED POST AGE 85



Note: Pre age 85 revenues may need to be set aside in a reserve fund to pay post age 85 cash flows

Table 2

EXAMPLE WHERE COHORT TAX REVENUE EQUALS COHORT INCOME TO BE FINANCED POST AGE 85

Cohort Age	Percent of Citizens Alive	Number of Citizens Alive Based on Population of Cohort	Average Income Equals AGI/# of Returns in Cohort	Total AGI	Tax Revenue @15%	Population to Cover (i.e., 25% of long-lived do not need insurance)	Average Individual Income Goal at Target Replacement Rate	Amount to be Financed if all from Bonds	Surplus/ Deficit (amount to be financed minus current revenue)	Replacement Goal (assuming SS equals 50% replacement of average lifetime income)
(1)	(2A)	(2B)	(3)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
		100			15%	50%				30.0%
55	100	100	$96,832	$9,683,166	$1,452,475		$29,049			
56	100	100	$96,832	$9,683,166	$1,452,475		$29,049			
57	100	100	$96,832	$9,683,166	$1,452,475		$29,049			
58	100	100	$96,832	$9,683,166	$1,452,475		$29,049			
59	100	100	$96,832	$9,683,166	$1,452,475		$29,049			
60	100	100	$96,832	$9,683,166	$1,452,475		$29,049			
61	100	100	$96,832	$9,683,166	$1,452,475		$29,049			
62	100	100	$96,832	$9,683,166	$1,452,475		$29,049			
63	100	100	$96,832	$9,683,166	$1,452,475		$29,049			
64	100	100	$96,832	$9,683,166	$1,452,475		$29,049			
65	100	100	$96,832	$9,683,166	$1,452,475		$29,049			
66	97.5	97.5	$77,246	$7,531,525	$1,129,729		$23,174			
67	95	95	$77,246	$7,338,409	$1,100,761		$23,174			
68	92.5	92.5	$77,246	$7,145,293	$1,071,794		$23,174			
69	90	90	$77,246	$6,952,177	$1,042,827		$23,174			
70	87.5	87.5	$77,246	$6,759,061	$1,013,859		$23,174			
71	85	85	$77,246	$6,565,945	$ 984,892		$23,174			
72	82.5	82.5	$77,246	$6,372,829	$ 955,924		$23,174			
73	80	80	$77,246	$6,179,713	$ 926,957		$23,174			
74	77.5	77.5	$77,246	$5,986,597	$ 897,990		$23,174			
75	75	75	$77,246	$5,793,481	$ 869,022		$23,174			
76	72.5	72.5	$77,246	$5,600,365	$ 840,055		$23,174			
77	70	70	$77,246	$5,407,249	$ 811,087		$23,174			
78	67.5	67.5	$77,246	$5,214,133	$ 782,120		$23,174			
79	65	65	$77,246	$5,021,017	$ 753,153		$23,174			
80	62.5	62.5	$77,246	$4,827,901	$ 724,185		$23,174			
81	60	60	$77,246	$4,634,785	$ 695,218		$23,174			
82	57.5	57.5	$77,246	$4,441,669	$ 666,250		$23,174			
83	55	55	$77,246	$4,248,553	$ 637,283		$23,174			
84	52.5	52.5	$77,246	$4,055,437	$ 608,315		$23,174			
85	50	50	$77,246	$3,862,321	$ 579,348	25	$23,174	$579,348	$0	
86	47.5	47.5	$77,246	$3,669,205	$ 550,381	23.75	$23,174	$550,381	$0	
87	45	45	$77,246	$3,476,088	$ 521,413	22.5	$23,174	$521,413	$0	
88	42.5	42.5	$77,246	$3,282,972	$ 492,446	21.25	$23,174	$492,446	$0	
89	40	40	$77,246	$3,089,856	$ 463,478	20	$23,174	$463,478	$0	
90	37.5	37.5	$77,246	$2,896,740	$ 434,511	18.75	$23,174	$434,511	$0	
91	35	35	$77,246	$2,703,624	$ 405,544	17.5	$23,174	$405,544	$0	
92	32.5	32.5	$77,246	$2,510,508	$ 376,576	16.25	$23,174	$376,576	$0	
93	30	30	$77,246	$2,317,392	$ 347,609	15	$23,174	$347,609	$0	
94	27.5	27.5	$77,246	$2,124,276	$ 318,641	13.75	$23,174	$318,641	$0	
95	25	25	$77,246	$1,931,160	$ 289,674	12.5	$23,174	$289,674	$0	
96	22.5	22.5	$77,246	$1,738,044	$ 260,707	11.25	$23,174	$260,707	$0	
97	20	20	$77,246	$1,544,928	$ 231,739	10	$23,174	$231,739	$0	
98	17.5	17.5	$77,246	$1,351,812	$ 202,772	8.75	$23,174	$202,772	$0	
99	15	15	$77,246	$1,158,696	$ 173,804	7.5	$23,174	$173,804	$0	
100	12.5	12.5	$77,246	$ 965,580	$ 144,837	6.25	$23,174	$144,837	$0	
101	10	10	$77,246	$ 772,464	$ 115,870	5	$23,174	$115,870	$0	
102	7.5	7.5	$77,246	$ 579,348	$ 86,902	3.75	$23,174	$ 86,902	$0	
103	5	5	$77,246	$ 386,232	$ 57,935	2.5	$23,174	$ 57,935	$0	
104	2.5	2.5	$77,246	$ 193,116	$ 28,967	1.25	$23,174	$ 28,967	$0	
105	0	0	$77,246	$ -	$ -	0	$23,174	$ -	$0	

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the actual creation of LIVE bonds would need further, detailed study. These LIVE bonds have several challenges.

First, the bond structure (because it has uncertain maturity) requires a declining annual income payment, but it then requires the individual to potentially engage in dynamic portfolio rebalancing. These calculations easily could be beyond the scope of the average eighty-five-year-old citizen. One possible way to address this issue could be to create a mutual fund per cohort (along the lines of Goldsticker 2007), whereby the mutual fund vendor conducts these calculations for each survivor.

Second, even if the calculations are delegated to a third party, the one major challenge with using the LIVE bonds and portfolio rebalancing approach is that individuals cannot commit upfront (say at age sixty-five) to buying these bonds and hedge longevity risk—the way LIVE bonds are designed. Individuals must keep adjusting the hedge, which does not make for a perfect hedge, and they must keep aside resources until death (especially because LIVE prices will keep changing every year). Again, the mutual fund approach might delegate the calculation of these amounts, but individuals still will need to keep paying new amounts to maintain their standard of living (unless rates rise dramatically, in which case the price of the bond could decline to offset the need for additional resources for more bonds). The mutual fund company could send out an annual statement—individuals could either increase holdings, liquidate them completely (and if they are dead, the heirs could do so), or settle for a lower level of longevity-hedged income. If Ebrahimi (2019) and table 3 is reality, then limited rebalancings may be required.

Further, those who die bequest the future proceeds to heirs; therefore, wealth is transferred from one generation to the next, but this overcomes a challenge of traditional annuities—no bequest. Alternatively, one could argue that we allow the bonds of the dead to expire worthless (i.e., moderate the number of bonds outstanding while holding the coupon fixed as in BFFS/SeLFIES). This would make for ease of planning by individuals (because they can buy a fixed amount on day one and then be guaranteed income until death), but the big challenge with this approach is that we must assume that the government is able to state that individuals can receive the proceeds only while they are alive (i.e., the bond expires worthless once you die). In addition to the challenge of having to monitor who is alive and who is dead, the government also will have to preclude the sale of the bond; otherwise, someone close to death will sell them as death looms. So, the challenge of monitoring and the drawback of zero liquidity led us to the approach of a declining coupon to potentially match the declining expenditure post retirement as in figure 3.

In addition to this complication, there are other issues. First, we do not know survival rates *ex ante* as assumed in tables 1 and 2. In this simple LIVE bond example, the coupon that would probably need to be pre-specified to allow for effective pricing is based on the survival rates post age eighty-five. Therefore, the government could bear some risk if the actual survival realization when the cohort ages from age eighty-five on is different from what might have been assumed when the bond is issued, e.g., when the cohort is fifty-five, sixty-five, or seventy-five. One way to manage this issue is that if the survival rate is higher than expected the government could either re-open the issue (and issue more bonds to support more survivors) or, alternatively, the government could permit a dividend that would be linked to the difference between the actual and assumed survival rate. However, the dividend idea would complicate the pricing of the bond because now it would have stock-like elements of uncertain cash flows.[12] The alternative is that the government guarantees the coupons, so that LIVE bond pricing is simplified, and the government bears the risk.

The good news with the first challenge is that the government (more than likely the Social Security Administration) will have detailed historical information about survival rates for different cohorts for each age in retirement. This could be helpful in forecasting the likely survival rate of a particular cohort and therefore the corrections might not be drastic. The more complex assumption is that a fixed percentage (e.g., 50 percent) of those surviving need to be covered by LIVE bonds. This data probably does not exist in a readily usable format because we have not tracked how many retirees seek to protect against longevity risk. The percentage of individuals who have purchased annuities (fewer than 10 percent) would suggest a low coverage ratio, but this could be solely because the current annuity instrument is complex and expensive. What happens if instead the actual coverage rate at the time of the initial bond issuance is higher? Further, what happens if the coverage rate varies every year thereafter (because there is no guarantee that an equal percentage of covered and uncovered members of the cohort die each year)? This could raise challenges for governments that have not reserved adequately for this contingency.

Third, most governments do not like to commit future revenues to prespecified purposes because dollars are fungible and they would like to retain flexibility regarding how to use the revenues. Therefore, LIVE bonds, despite their potential appeal to help individual longevity risk, may not be favored by governments because they specifically tie down governments to future revenue streams.

Once a government creates such a bond that ties coupon payments to a cohort's revenue, then there is the potential for additional innovation. For example, in the extreme, the definition of a cohort could be narrowed even further to gender-specific LIVE bonds. After all, women live longer than men and therefore have greater longevity risk, so they probably

need more protection than men. In this fashion, creative governments can address specific issues they deem worthy of attention.

CONCLUSIONS

There is an annuity puzzle in that despite the welfare gains to individuals and society from consumers purchasing annuities, the actual allocation to these instruments by individuals is low. Many explanations have been provided including adverse selection, complexity and inflexibility of the annuity contract, bequest motive, etc. Insurance companies have tried to address these issues by changing their products, but adoption still has been low. Some have argued that governments should create and issue longevity bonds that attempt to hedge overall economy-wide mortality risk to improve insurance companies' ability to hedge their annuity offerings, thereby lowering costs. But these longevity bonds have challenges and although an "improving social-welfare" case can be made for why governments should issue such bonds, these proponents have not shown how governments have a natural hedge.

Instead, we suggest governments should create LIVE bonds. These bonds, targeted to individuals (and institutions) would pay income only, and start paying only after the average life expectancy of society (having addressed retirement income through life expectancy with a complementary BFFS/SeLFIES bond). Each bond will be cohort-specific and based on tax collections of that cohort. The coupons will decline over time because tax revenues decline, in part because individuals also are dying. In this fashion, the government is fully hedged (because the bond will be a form of a CDO or CRO), and therefore a natural issuer, with low credit risk. Because BFFS/SeLFIES cover the life expectancy of those whose lives are shorter than the average, only those individuals who live beyond the average (usually wealthy portions of the population) and with limited resources need to purchase LIVE bonds. This paper also briefly discussed the portfolio strategies of those living beyond average life expectancy and how governments can ensure that they have sufficient funds to bear this risk.

The LIVE bond idea appears to address many, if not all, challenges posed by annuities and therefore is advantageous to individuals—the instrument is liquid, flexible, and has low-to-no credit risk. There is the ability to bequeath these bonds. Further, there is no issue of adverse selection. Reducing many of these challenges, and creating a liquid and tradable instrument, should greatly lower the cost.

In this paper, we take on the challenge of hedging longevity risk at the individual level through a liquid, low-cost, and low-credit risk option by leveraging an insight from our founding father, Benjamin Franklin who said, "In this world nothing can be said to be certain, except death and taxes."

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ACKNOWLEDGMENTS

Thanks to Profs. Robert C. Merton, Kazuhiko Ohashi, and Sunghwan Shin and Dr. Adam Kobor for collaborations on SeLFIES. Thanks to Prof. Jim Poterba for kind assistance with the data. All errors are the author's.

APPENDIX A: SOCIAL SECURITY VS. PROPOSED BOND AS A WAY TO HEDGE LONGEVITY RISK[13]

Most social security systems globally offer pension payments until death. However, there are some challenges to using this longevity insurance to protect retirees. The positive aspect of Social Security is that all workers who contribute get it and it is mandatory (with some exceptions for workers who have opted out). However, the cost to society is high because it

Table A1

A1: COMPARING SOCIAL SECURITY TO LIVE BONDS FOR LONGEVITY RISK MANAGEMENT

	Social Security	LIVE Bonds
Mandatory/Voluntary	Mandatory—everyone gets it	Voluntary—those who outlive average life expectancy and who want it
Cost	Potentially high because everyone is covered	Relatively low because only a small portion of population is covered
Intergenerational wealth transfer	Yes, future generations could bear cost	No—current cohort bears cost
Who bears the cost	Short-lived individuals (typically poor and minorities) transfer wealth to long-lived (typically wealthier individuals and from the majority population)	The long-lived bear the cost—prevents unintended wealth transfer from poor to rich
Simplicity	Trivial	Somewhat complex—uncertain cost, requires rebalancing
Liquidity	None	Liquid
Bequest	Not traditional (except for spousal benefits)	Yes, heir inherits bonds
Funded/Unfunded	Un- or partially funded	Fully funded
Inflation protection	Cost of living	Requires purchase of additional units over time to maintain standard of living

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must cover everyone, and in most countries, social security is severely underfunded and pay-as-you-go; therefore, this burden and cost is passed on to future generations (Modigliani and Muralidhar 2004). The other challenge with offering such longevity insurance is that short-lived individuals (typically the poor) are subsidizing the rich, which runs counter to basic principles of fairness (i.e., if anything it should be the other way around). The good news is that Social Security longevity risk insurance requires no effort on the part of the individual, but the converse to this is that it may be insufficient (because the average Social Security payment is approximately $15,000 per year—not a sustainable retirement income). There is some ability to bequeath these benefits (because there are spousal benefits). Table A1 contrasts the longevity insurance provided by Social Security versus the longevity insurance provided by LIVE bonds.

APPENDIX B: ASSUMPTIONS FOR BASIC MODEL

We make a number of simplifying assumptions to show how this bond could be designed and each can be made more complicated once we obtain real data from various sources.

Life expectancy: We start with an assumption about life expectancy at age sixty-five. Given that the average life expectancy is twenty years, we assume that 2.5 percent of the population alive at age sixty-five passes away every year. At age eighty-five, 50 percent of the population is alive; at age 105, the entire cohort has passed away.

Target replacement rate: We assume that individuals seek only 20 percent to 30 percent of their retirement income from private savings because Social Security covers 50 percent of their lifetime average income. Therefore, the combination gives an individual an approximately 60-percent to 70-percent replacement rate.

Average income of the cohort: We take the data from IRS Table 1.5 (2015), estimated at $96,832 for fifty-five to sixty-five-year-olds and $77,246 for age sixty-five and older.[14] There is no additional granularity from the IRS by each year, so we assume these are constant. Moreover, although we are mixing data from different cohorts, we assume that the current fifty-five to sixty-five-year-olds will have the same experience when they turn sixty-five and age as the current sixty-five and older cohort.

Percentage of citizens who need longevity risk protection: We make a simplifying assumption that the poor have a life expectancy that is less than the average, and the rich are the only ones who live longer than the average. Further, not all rich individuals need to buy longevity risk protection because some have sufficient resources. Therefore, only a fraction of those who live past age eighty-five need to worry about purchasing LIVE bonds.

Number of individuals filing returns: We assume that everyone alive at time t files returns. The IRS provides only the number of returns filed, which we have used as a proxy for this calculation. Therefore, it is likely to overstate the average income (because many returns are filed jointly). In such a case, it will not change the overall analysis because one might have to change to replacement rate to get the target retirement income level.[15]

Average tax rate: "Taxes paid rose to $1.45 trillion for all taxpayers in 2015, a 5.8-percent increase over the previous year. The average individual income tax rate for all taxpayers rose slightly, from 14.16 percent to 14.34 percent, and the average tax rate increased for all groups except the top 1 percent."[16]

ENDNOTES

1. This is surprising because Yaari (1965), more than fifty years ago, demonstrated that with uncertain death, there is potentially a mortality premium. This premium is captured by eliminating mortality risk (the converse of longevity risk) because individuals could exchange a lump sum today for an annuity and be assured, with some credit risk, that they can sustain their consumption at a guaranteed level for the rest of their lives. However, in order to earn this "mortality premium," the individual often has to give up bequests. Brown and Orzsag (2006) demonstrate further that there are welfare gains at an individual level to purchasing annuities and welfare benefits at the societal level. For example, individuals may have the incentive to spend their financial wealth too quickly, knowing that if they live longer than anticipated and run out of money, they simply can rely on the government to provide benefits. Conversely, individuals may constrain consumption (or be expected to work potentially even in retirement) to preserve resources, which could act as a brake on economic growth.
2. Salisbury and Nenkov (2016) note, "Companies offering annuities have adjusted their products in an effort to accommodate proposed explanations and make annuities more attractive by introducing options such as fixed terms, bequeath features, and deferred start dates, with little effect on the rate of annuitization."
3. See Brown (2014), Muralidhar (2016), Muralidhar et al. (2016), Merton and Muralidhar (2017a, b, c, 2018a, b, 2019).
4. For example, public sector workers often receive DB pensions for full service that approach 70 percent of average lifetime earnings, which historically has been considered an adequate pension, see Aon (2008). These individuals may not need longevity risk insurance. One could argue that this is more of an issue for private sector workers who depend on Social Security (offering a 55-percent replacement rate of lifetime average income for low-income workers and much-lower replacement rates for higher-income workers) and who also depend on private savings to cover the balance. Thanks to an anonymous reviewer for this clarification.
5. See Muralidhar (2016).
6. Refer to Merton and Muralidhar (2019) for an explanation for how this mechanism of converting SeLFIES to annuities would take place.
7. We assume that the payment is referenced in nominal currency—i.e., pound sterling per bond—and not a coupon rate, because this is not immediately obvious in the papers.
8. Merton and Muralidhar (2019) argue for extending the maturity by a few years if governments want to use SeLFIES in exchange for annuities from insurance companies.
9. Thanks to an anonymous referee for this helpful comment.
10. See https://www.ssa.gov/oact/STATS/table4c6.html.
11. Thanks to an anonymous referee for this helpful comment.
12. In a variant of the structure proposed, if the LIVE bond is designed as a pure CRO, then the bond would be priced more like a stock.
13. I am extremely grateful to Kazuhiko Ohashi, Sunghwan Shin, and Rui Ferreira for discussions on this appendix.
14. This calculation is made by dividing the total adjusted gross income of the cohort by the number of returns.
15. Thanks to an anonymous referee for this clarification.
16. See taxfoundation.org.

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