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Long-Run Biological Interest Rate for Pay-As-You-Go Pensions in Advanced and Developing Countries

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Long-Run Biological Interest Rate for Pay-As-You-Go Pensions in Advanced and Developing Countries[1]

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Abstract

How much of an internal rate of return would a sustainable pay-as-you-go pension system offer current and future generations equally? The answer is the sum of the Long-Run Biological Interest Rates (LBIR), the real-world equivalent of Samuelson's (1958) biological interest rate, and future productivity growth. Reflecting global population ageing, the median LBIR across 172 countries is as low as 1 percent per year. The LBIRs are particularly low in advanced countries, estimated to be negative in many of them, and require ample financial reserves today or future productivity growth to maintain participation in pension schemes. On the other hand, the LBIRs in less developed regions, such as in sub-Saharan Africa, are relatively high, indicating a potential to use a pay-as-you-go scheme to expand the coverage of public pensions. Raising the retirement age by five years brings up the LBIR by 40 basis points, significantly improving the long-run budget constraint of a pension scheme.

JEL Classification Numbers: E62, H55, J11

Keywords: Pay-as-you-go pension, internal rate of return, pension reform

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I. Introduction

Public old-age pensions provide insurance against post-retirement income losses. Broadly speaking, an old-age pension system is run either as a pay-as-you-go scheme, where contributions from the working-age population are used to pay for pension benefits for the retired in the current period, or as a funded scheme, where workers' contributions are invested in financial assets that pay for their own retirement benefits. The pay-as-you-go scheme is more common in practice,[2] while its sustainability hinges on demographic prospects. In fact, in many advanced countries, population ageing has posed challenges in maintaining pay-as-you-go schemes and prompted reforms.

The sustainability of a pay-as-you-go pension system rests ultimately on whether it offers an adequate internal rate of return for current and future generations. If not, working-age individuals opt out and stop contributing to the system. Their exits would leave unfunded liabilities for paying pension benefits to current and future retirees, or defaults of the liabilities would push the pension-dependent elderly into poverty. Facing political pressure, policymakers may be tempted to design pay-as-you-go systems that offer attractive internal rates of return for living generations, at costs with lower internal rate of returns for generations yet to be born. Such Ponzi-like schemes would become unsustainable as soon as it becomes clear that the pension systems could not promise adequate internal rates of return for young generations.

In this context, this paper aims to estimate the internal rate of return that a sustainable pay-as-you-go pension scheme would offer current and future generations. In a simple textbook model of overlapping generations, the internal rate of return for a sustainable pay-as-you-go pension scheme equals the growth rate of the contributions collected from the working-age population. This in turn is decomposed into working-age population growth and productivity growth. Observing this, Samuelson (1958) referred to population growth as the "biological interest rate."

This paper applies this idea to the real world. It develops an equivalent of Samuelson's biological interest rate in a general, non-steady-state overlapping generation economy, calling it the Long-Run Biological Interest Rate (LBIR). The LBIR is then estimated for a pay-as-you-go pension scheme that is sustained over 2015–2100 in each of 172 countries, using the United Nation's age-by-age population projection data (United Nations, 2015). Because the internal rate of return for a sustainable pay-as-you-go pension scheme equals the sum of the LBIR and future productivity growth, a country with a low LBIR would need high productivity growth to provide and maintain an adequate internal rate of return for a pay-as-you-go pension system. The LBIR would serve as a useful benchmark even for countries with funded pension schemes by clarifying what a pay-as-you-go alternative could offer.

Two issues are worth noting in evaluating the LBIR estimates. First, the pay-as-you-go scheme would have to provide pensions for the elderly during its initial years, even though they have never contributed into the scheme. This initial cost is accounted for in the LBIR estimate.

[2] Defined-benefit, earnings-linked pensions are publicly provided in 20 out of 34 OECD countries (OECD, 2015).

Second, it is assumed that the pay-as-you-go pension scheme can accumulate financial reserves to save for rising pension payments in the future, a standard practice in many countries.[3] Conditional on a projected demographic path, such a scheme can promise a *uniform* LBIR for current and future generations. This approach ensures inter-generational equity by construction, an advantage over traditional approaches, such as generational accounting, that tend to be complex and data-demanding. For simplicity, it is assumed that there are no financial reserves at the beginning of the pension scheme.

The key findings of this paper are summarized as follows. First, LBIRs are globally low. The median LBIR for 172 countries is estimated to be as low as 0.9 percent per year, with LBIRs estimated to be negative in 54 countries. Adding historical productivity growth as a proxy for future productivity growth, one can gauge the corresponding internal rate of return for a pay-as-you-go scheme. The median internal rate of return for 172 countries calculated this way is 2.4 percent per year, only marginally exceeding the U.S. risk-free rate of return over the past decades. The internal rates of return are estimated to be negative in 13 countries.

Second, LBIRs vary widely across country groups. In advanced countries, where population ageing has progressed much faster than in developing countries, the median LBIR is -0.6 percent per year, and the LBIRs are estimated to be negative in 31 out of 34 countries. The median of the LBIR plus historical productivity growth is only 1.4 percent per year for this group. Looking at developing countries by region, the median LBIR is slightly negative at -0.1 percent per year in emerging Europe and the Commonwealth of Independent States (CIS), but it is relatively high in sub-Saharan Africa (2.8 percent) and in the Middle East and North Africa (1.6 percent). The LBIRs plus historical productivity growth are relatively high in developing Asia (the median is 3.8 percent) and sub-Saharan Africa (3.4 percent). The former is supported by high historical productivity growth while the latter benefits from the region's high LBIRs.

Third, raising the retirement age can ratchet up the LBIR. Setting a higher retirement age by five years (from 65 to 70) increases the LBIR by around 40 basis points on average, with the increase being similar across countries, regardless of the LBIR levels. This finding supports raising the retirement age as an effective policy lever for improving the sustainability of a pay-as-you-go pension scheme.

Fourth, fertility prospects have a substantial impact on the LBIR. The LBIRs are calculated under low- and high-fertility scenarios considered by the United Nations' population projections (United Nations, 2015). These scenarios represent extreme events for most of the countries in the sample, except sub-Saharan African countries. On average, the LBIR would be about 0.5 percentage points lower (higher) under the low-fertility (high-fertility) scenario than under the medium-fertility scenario.

Finally, the LBIR affects the size of pension benefits relative to pension contributions. I define the Replacement-Contribution Ratio (RCR) as the ratio of the pension replacement rate (i.e., pension benefits as a percent of wages) to the contribution rate (i.e., pension contributions as a percent of wages) for a sustainable pay-as-you-go pension scheme. The RCR is positively

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[3] Public pensions hold reserve funds in 16 out of 34 OECD countries (OECD, 2015).

associated with the LBIR because a higher internal rate of return increases the amount of pension benefits. In advanced countries, the RCRs are particularly low, reflecting their low LBIRs; the median RCR is 2, implying that a replacement rate of 50 percent requires a contribution rate as high as 25 percent. In startling contrast, the median RCR in sub-Saharan Africa is as high as 8.6, thanks to its high LBIR, implying that a replacement rate of 50 percent requires a contribution rate as low as 6 percent. Raising the retirement age improves the RCR not only by lengthening the contribution period and shortening the retirement period but also by ratcheting up the LBIR. The median RCR for all countries improves from 3.5 to 5.5 when the retirement age is raised from 65 to 70. Fertility prospects also affect the RCR—the median RCR decreases (increases) from 3.5 to 3.0 (4.1) under the low-fertility (high-fertility) scenario, as opposed to the medium-fertility scenario.

This paper contributes to the literature by estimating the internal rates of return for pay-as-you-go pensions in most of the countries across the world, based on a generalized framework. Settergren and Mikula (2005) show that the internal rate of return for a pay-as-you-go pension entails not only the biological interest rate but also shifts in income and mortality patterns. Knell (2016) shows that a rise in life expectancy increases the internal rate of return for a pay-as-you-go pension scheme. However, these two papers do not fully take account of non-steady-state population dynamics. Ediev (2014) estimates the internal rate of return for a pay-as-you-go pension scheme in 24 advanced countries and finds the positive relationship between the return and life expectancy. His paper differs from this one in that the estimated internal rate of return is not uniform across generations, but rather age-cohort specific. In other words, the internal rate of returns depends on the year in which the individual is born, because his model assumes that contributions from the working-age population is fully utilized to finance pension payments for retirees in each period.

The rest of the paper is organized as follows. Section II introduces the methodology in detail and defines the LBIR under a generalized overlapping generation model. Section III presents estimates of the LBIR across countries. The RCR is analyzed in Section IV, which discusses the implications of the low- and high-fertility scenarios in Section V. Section VI concludes by discussing policy implications and highlighting the merits of this paper’s analytical framework vis-à-vis traditional methodologies. Country classifications are reported in Appendix I, and country-by-country estimates of the LBIR, together with other demographic and pension indicators, are presented in Appendix II.

II. Setup

The internal rate of return for a public pension scheme refers to the rate that equalizes contributions and pension benefits from individual participants’ perspective. In a standard two-period overlapping generation model, the internal rate of return for a pay-as-you-go pension scheme equals the growth rate of the contribution base, that is, the sum of population growth—Samuelson (1958) called this as the “biological interest rate”—and productivity growth. This is intuitive: contributions from the working-age generation in a given period—which are fully used to pay pension benefits to the retired generation in that period—increase in tandem with the number of workers, as well as the productivity growth that results in higher wages. Note that retirees in the initial period of the scheme receive pensions even though they contributed nothing.[4]

I build up a framework that applies this idea to the real world. I aim to estimate the highest internal rate of return that a sustainable pay-as-you-go pension can offer equally for current and future generations in a given country. This exercise would be useful not only for countries whose public pension system is primarily pay-as-you-go, but also for those with funded pension schemes by clarifying what a pay-as-you-go alternative could offer. I consider a public pension scheme where workers contribute a portion of wage income to a nationally pooled fund, and retirees receive pensions from that fund. The pension scheme promises a uniform internal rate of return for all current and future generations, assuring inter-generational equity. The pension scheme needs to be sustainable, that is, the present value of contributions over time needs to be at least as large as the present value of pension payments over time. It can borrow to finance a temporary cash shortfall or accumulate reserves for future pension payments (in this sense, the pension scheme differs from a pure pay-as-you-go scheme where worker contributions are fully used to pay for pension payments in each period).

To be specific, consider the following overlapping generation economy. In a given year t, all individuals in the labor force receive the same real wage, $W(t)$, regardless of age. Real wages grow over time at a time-invariant rate of productivity growth denoted by μ, so $W(t+1) = (1+\mu)W(t)$. A pension scheme is established in year T_0. Workers are obliged to contribute at a fixed contribution rate c, starting at age A_0 and continuing up until one year before the retirement age at A_1. From the perspective of an individual, contributions are invested and accumulated in her notional pension account. The account earns a rate of return denoted by θ, which is time invariant and is the same for all individuals regardless of year of birth. Individuals retire and leave the labor force at age A_1, when they receive the balances in their notional accounts as lump-sum pension benefits.

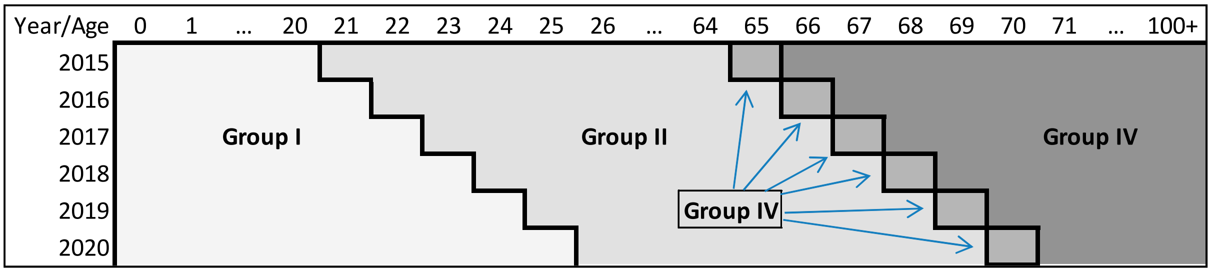
In the early years of the pension scheme, the elderly receive pension benefits, even though they have contributed nothing or have done so for fewer years than the number of years that encompass the regular contribution period ($A_1 - A_0$). To clarify this, I divide the population into four groups as illustrated in Table 1 and Figure 1:

Table 1. Definition of Generation Groups

Group	**Age as of year T_0**	**Number of years to contribute**
Group I	$\leq A_0$ (including those not yet born)	$(A_1 - A_0)$
Group II	Between A_0 and A_1	Less than $(A_1 - A_0)$
Group III	$= A_1$	0
Group IV	$> A_1$	0

[4] In a standard overlapping generation model, the internal rate of return for a funded pension scheme equals the market interest rate, which can be larger than the internal rate of return for a pay-as-you-go scheme (the so-called Aaron (1966) condition). Even if this is the case, the difference in the internal rates of return of the two schemes is fully explained by the initial cost for a pay-as-you-go pension that offers pensions to the elderly with no contribution records. See Sinn (2000), Fenge and Werding (2003), and Blake (2006) for details.

Figure 1. Population Structure by Generation Group and Age



Source: Author.
Note: This table illustrates how the population is divided into Groups I–IV, with the contribution starting age (A_0) set at 20, the retirement age (A_1) at 65, and the starting year of the pension scheme (T_0) at 2015.

For Group I individuals, the pension scheme exists when they enter the labor force. Their contributions made in year $t-k$ become $cW(t-k)(1+\theta)^k$ in year t in their notional accounts. An individual retiring in year t contributes from year $t-(A_1-A_0)$ to year $t-1$. Thus, aggregating contributions over years, she receives in year t a lump-sum pension benefit of

$$\Psi(t) \equiv \sum_{k=1}^{A_1-A_0} cW(t-k)(1+\theta)^k = cW(t)\sum_{k=1}^{A_1-A_0}\left(\frac{1+\theta}{1+\mu}\right)^k . \quad (1)$$

Group II, III, and IV individuals receive pensions despite incomplete contribution histories. I assume that a Group II individual retiring in year t also receives $\Psi(t)$ as if she has contributed fully, although the pension scheme does not exist when she joins the labor force. Similarly, a Group III individual, whose age is A_1 in year T_0, receives $\Psi(T_0)$ even though she has not contributed at all. Group IV individuals receive pension benefits equivalent of those for Group III individuals in annual installments rather than as a lump-sum payment. Starting at year T_0 and over her lifetime, a Group IV individual receives annual pensions denoted by $\Lambda(\mathrm{t})$. For year T_0, $\Lambda(\mathrm{t})$ is set at an amount equal to $\Psi(T_0)$ divided by the years of remaining life expectancy for Group III individuals at age A_1; so $\Lambda(\mathrm{T}_0) = \Psi(T_0)/B$, where B is the remaining life expectancy of individuals of age A_1 in year t. This treatment takes into account the prospect that Group IV individuals would have relatively short remaining life expectancy at year T_0. For instance, an individual of an age much greater than A_1 and a few years of remaining life expectancy would not need to receive $\Psi(T_0)$. I assume that $\Lambda(\mathrm{t})$ increases by productivity growth each year, so $\Lambda(\mathrm{T}_0+\mathrm{s}) = \left(\frac{\Psi(T_0)}{B}\right)(1+\mu)^s$. This ensures that the replacement rate of the pension benefit, defined by $\Lambda(t)/W(t)$, remains constant over time.

The national pension fund collects contributions from workers and pays pension benefits to retirees each year. In year t, the working-age population $N_w(t)$ comprises individuals whose ages fall between A_0 and A_1-1. In each year starting T_0, individuals who belong to Groups I, II, and III and reach the age of A_1 retire; the number of such individuals in year t is denoted by $N_{r1}(t)$. The number of Group IV individuals in year t is denoted by $N_{r2}(t)$. In year t, the fund collects contributions from working-age individuals, denoted by $R(t) \equiv cW(t)N_w(t)$; it pays the lump-sum pension benefits to retiring individuals who belong to Groups I, II, and III, denoted by $G_1(t) \equiv \Psi(t)N_{r1}(t)$; and it also pays annual pension benefits to Group IV individuals, denoted by $G_2(t) \equiv \Lambda(t)N_{r2}(t)$.

The pension fund can invest in an asset that yields a time-invariant interest rate of r, or can borrow at this interest rate. I assume that r equals the sum of annual productivity growth, average working age population growth (l), and a positive interest-rate-growth-differential ($irgd$):

$$1 + r = (1 + \mu)(1 + l)(1 + irgd), \quad irgd > 0. \tag{2}$$

The long-run sustainability of the system requires the present value of collected contributions to be larger than or equal to the present value of pension benefit payments:

$$\sum_{s=0}^{\infty} \frac{R(T_0 + s)}{(1 + r)^s} \geq \sum_{s=0}^{\infty} \frac{G_1(T_0 + s) + G_2(T_0 + s)}{(1 + r)^s}. \tag{3}$$

The highest internal rate of return for the pension scheme, denoted by θ^*, is the largest value of θ that satisfies (3) above. Because the left-hand side is independent of θ and the right-hand side is a monotonically increasing function of θ, θ^* is uniquely determined as the value that equalizes both sides of (3). Rearranging terms, θ^* satisfies

$$\sum_{s=0}^{\infty} \left(\frac{1 + \mu}{1 + r}\right)^s N_w(T_0 + s) = \sum_{k=1}^{A_1 - A_0} \left(\frac{1 + \theta^*}{1 + \mu}\right)^k \sum_{s=0}^{\infty} \left(\frac{1 + \mu}{1 + r}\right)^s \left\{N_{r1}(T_0 + s) + \frac{1}{B} N_{r2}(T_0 + s)\right\}. \tag{4}$$

It is convenient to strip off productivity growth from the pension's internal rate of return. I define ϕ as the internal rate of return obtained after netting out productivity growth from θ^*:

$$\phi \equiv \frac{1 + \theta^*}{1 + \mu} - 1. \tag{5}$$

Plugging (5) into (4) results in:

$$\sum_{k=1}^{A_1 - A_0} (1 + \phi)^k = \frac{\sum_{s=0}^{\infty} \frac{1}{(1 + l)^s (1 + irgd)^s} N_w(T_0 + s)}{\sum_{s=0}^{\infty} \frac{1}{(1 + l)^s (1 + irgd)^s} \left\{N_{r1}(T_0 + s) + \frac{1}{B} N_{r2}(T_0 + s)\right\}} \tag{6}$$

I call ϕ as *the Long-Run Biological Interest Rate* (LBIR). Equation (6) shows that the LBIR can be computed from demographic prospects and an assumed value of the interest-and-growth-rate-differential.

In sum, the highest internal rate of return that a sustainable pay-as-you-go pension can offer equally for all generations is given by the LBIR plus future productivity growth. This approach provides a simple and tractable framework for analyzing the fundamentals of pay-as-you-go pensions in a given country. Note that estimating the LBIR does not require any knowledge of the characteristics of existing pension systems (contribution rate, benefit formula, etc.), which vary significantly by country. In this framework, I assume no financial assets are available in year T_0 to finance future pension benefits; if they are available, the internal rate of return would be higher than the LBIR plus productivity growth.

III. Estimating LBIR in Advanced and Developing Countries

In this section, I estimate the LBIR for 172 countries. For each country, the LBIR is calculated by numerically solving equation (6) for ϕ. The pension scheme is introduced in 2015 (so T_0 is 2015) with the end year being 2100. Demographic data are taken from the latest United Nations (UN) projection (United Nations, 2015, *2015 Revision of the United Nations World Population Prospects,* the medium fertility variant).[5] Specifically, (i) $N_w(t)$, $N_{r1}(t)$, and $N_{r2}(t)$ are computed from the annual population projection for 2015–2100; (ii) l is calculated as the average rate of increase in the population of ages 20–64 over 2015–2100; and (iii) B is taken from projected remaining life expectancy at age 65 as of 2015. The age at which individuals start contributing (A_0) is set at 20 and the retirement age (A_1) is set at 65 for all countries to facilitate cross-country comparisons.[6] The interest-rate-growth-differential ($irgd$) is set at 1 percent per year, following the approach by Clements and others (2015).[7] I will present sensitivity analyses for alternative values of A_1 and $irgd$. The dataset allows us to compute the LBIRs for as many as 172 countries, consisting of advanced countries and middle- and low-income countries in various regions. See Appendix I for the composition of country groups by income and region.

The UN projection suggests that the population will age in the long run, not only in advanced countries, but also in developing countries. For the countries in this dataset, the average old-age dependency ratio, that is, the ratio of the elderly (age 65 and older) to the working age population (between ages 20 and 64), is projected to increase from 14 percent in 2015 to 50 percent in 2100. Similarly, the average long-run growth rate of the elderly (2 percent per year over 2015–2100) exceeds that of the working age population (0.4 percent). In fact, the population will age faster in developing countries than in advanced countries. For middle- and low-income countries, the old-age dependency ratio more than quadruples between 2015 and 2100. These reflect the global trend of falling fertility and increasing longevity. The question is how this trend translates into the LBIR in each individual country.

The main results of this paper are shown in Table 2, which reports the summary statistics of the estimated LBIR along with demographic indicators (see Appendix II for country-by-country LBIR estimates). Key observations are as follows:

- Global population ageing translates into a generally low LBIR. The median LBIR for all 172 countries is as low as 0.9 percent per year. The range of the LBIR is somewhat wide,

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[5] Under this variant, net migration is generally assumed to remain constant until around 2050 and decrease gradually decline thereafter, while recent developments such as refugee flows and temporary labor flows are taken into account (United Nations, 2015). See Clements and others (2015) for discussions of these migration assumptions.

[6] For OECD countries, the average normal retirement age for defined benefit public pension schemes is 63.3 years (OECD, 2015). The LBIR estimates for alternative values of the retirement age are available from the author upon request.

[7] To estimate the net present value of age-related public spending on pension and healthcare in the future, Clements and others (2015) assume that the interest rate-growth differential converges in the long run to 1 percent, the average observed in the advanced economies over the past 25 years.

with the standard deviation of 1.5 percent, the minimum of -1.4 percent, and the maximum of 4.1 percent.

- Comparing the LBIRs across country groups, the median LBIR for advanced countries is negative (-0.6 percent) and lower than that for middle-income countries (0.6 percent) and low-income countries (2.8 percent). Among developing countries, the median LBIR is negative for emerging Europe and CIS countries (-0.4 percent), while it is relatively high for sub-Saharan Africa (3.0 percent) and the Middle East and North Africa (1.7 percent). The median for developing Asia (1 percent) and Latin America and the Caribbean (0.6 percent) lies in the middle.

- The LBIR is negative in as many as 54 countries, being about 30 percent of the total. Most of the advanced countries have negative LBIRs (31 out of 34 countries), and so do more than half of the countries in emerging Europe and the CIS (16 out of 23 countries). In these countries, the internal rate of return for a pay-as-you-go pension system would be negative unless productivity growth is sufficiently high.

- The variation of the LBIR across countries reflects the degree of population ageing at present and in the future, as expected. The LBIR is correlated negatively with the old-age dependency ratio in 2015 and 2100, and positively with the projected long-run growth rate of the working-age population (see Figure 2).

Table 2. LBIR Estimates and Demographic Indicators

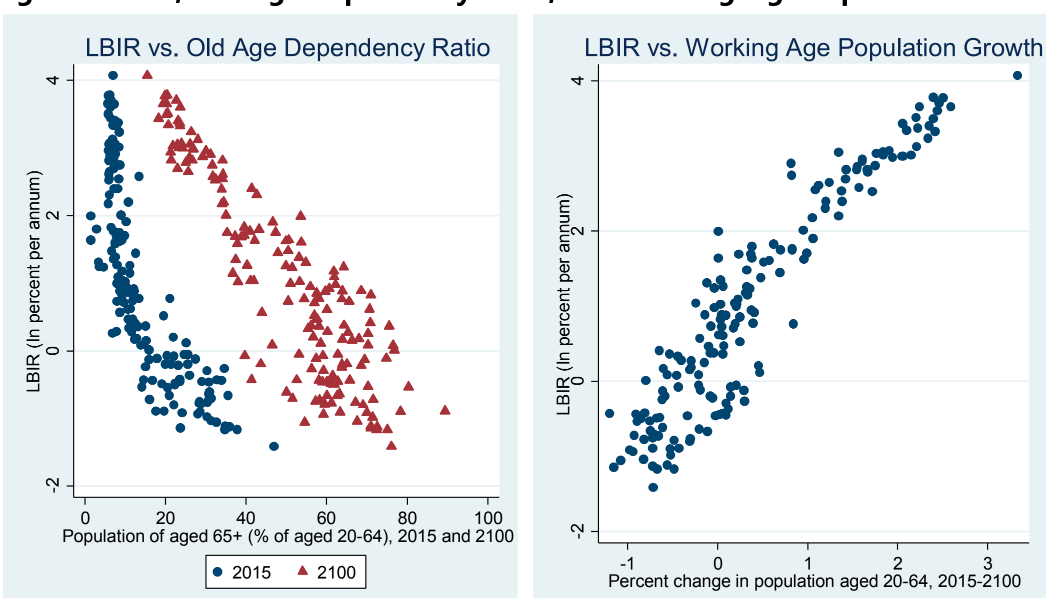
	Long-Run Biological Interest Rate (LBIR) (% per annum)					Number of countries with negative LBIR	Number of countries	Dependency ratio in 2015 (%) 1/	Dependency ratio in 2100 (%) 1/	Working-age population growth (%) 2/	Old-age population growth (%) 3/
	Mean	Median	St. dev.	Max.	Min.	Count	Count	Mean	Mean	Mean	Mean
All countries											
All countries	1.0	0.9	1.5	4.1	-1.4	54	172	14.4	49.7	0.4	2.0
By income group											
Advanced	-0.5	-0.6	0.5	0.8	-1.4	31	34	28.7	63.8	-0.2	0.8
Middle income	0.7	0.6	1.0	3.8	-1.1	22	82	13.2	54.9	0.0	1.8
Low income	2.5	2.8	1.0	4.1	-0.4	1	56	7.5	33.5	1.4	3.1
By region											
Advanced	-0.5	-0.6	0.5	0.8	-1.4	31	34	28.7	63.8	-0.2	0.8
Emerging Europe and CIS	-0.1	-0.4	1.0	2.2	-1.1	16	23	19.1	54.1	-0.5	0.8
Developing Asia	1.0	1.0	0.9	2.6	-0.7	3	19	9.9	54.7	0.2	2.2
Latin America and the Caribbean	0.6	0.6	0.6	1.9	-0.5	3	30	13.3	59.9	0.0	1.8
Middle East and North Africa	1.6	1.7	0.8	3.0	0.1	0	22	7.1	46.7	0.5	2.9
Sub-Saharan Africa	2.8	3.0	0.9	4.1	-0.2	1	44	7.3	28.9	1.7	3.3

Source: Author's calculations based on the UN Population Projection (United Nations, 2015).
1/ Population aged 65 and over in percent of population of ages 20–64.
2/ Annual percent change in population of ages 20–64, averaged over 2015–2100.
3/ Annual percent change in population of ages 65 and over, averaged over 2015–2100.

The low levels of LBIRs across the world present challenges for maintaining pay-as-you-go pension schemes over the long run. In a country with a low LBIR, high productivity growth would be necessary to provide future generations with adequate internal rates of return; otherwise, they will have incentive to opt out of the pension scheme and choose alternative options for their retirement savings. In this case, a vicious cycle would emerge: low participation would erode the contribution base, bring down the internal rate of return, and induce further opt-outs.

To explore this point quantitatively, I estimate the LBIR plus productivity growth, along with alternative investment options. Historical productivity growth, measured as the average real per-worker GDP growth rate over 1990–2010, is used as a proxy for future productivity growth. The median productivity growth for all countries in the dataset was 1.5 percent per year during this period. Looking at variations across groups, developing Asia achieved the highest productivity growth (the median is 3.0 percent), followed by emerging Europe and the CIS (1.8 percent) and advanced countries (1.7 percent). The average productivity growth was relatively low in Latin America and the Caribbean (1.0 percent), the Middle East and North America (0.9 percent), and sub-Saharan Africa (0.5 percent). Using the past average as proxy for long-run productivity growth may prove to be optimistic, given that productivity growth is expected to decline in the years ahead in advanced and emerging market economies (IMF, 2015). The LBIR plus historical productivity growth is compared with the risk-free real interest rate, represented by the short-term U.S. real interest rate. It averaged 2.1 percent per year over 1970–2010. Another alternative investment option is represented by the real rate of return for the S&P 500, which averaged 6.8 percent over 1970–2010. This alternative serves an illustrative purpose; needless to say, risky asset returns need to be weighed against risks, and a simple comparison of average returns would be misleading.

Figure 2. LBIR, Old-Age Dependency Ratio, and Working-Age Population Growth

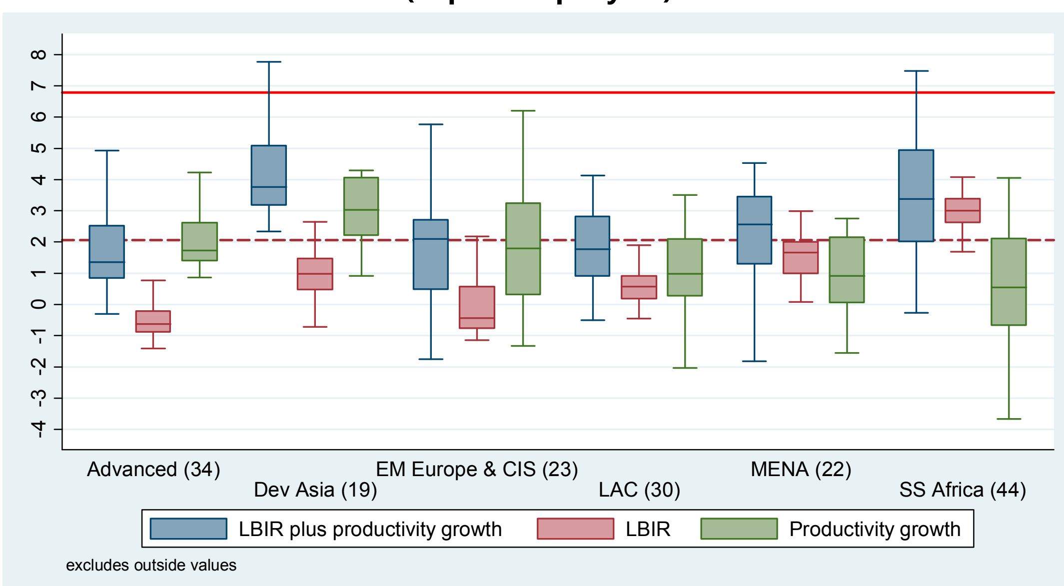


Source: Author's calculations.

The results are reported in Figure 3. The median internal rate of return for 172 countries, measured by the LBIR plus historical productivity growth, is 2.4 percent per year. This is slightly above the risk-free benchmark of 2.1 percent. The median for advanced countries (1.4 percent) and Latin America and the Caribbean (1.8 percent) is below this benchmark, while those for emerging Europe and the CIS (2.1 percent) and the Middle East and North Africa (2.6 percent) marginally exceed the benchmark. In contrast, the estimated internal rate of return is relatively high in developing Asia (median of 3.8 percent) and sub-Saharan Africa (3.4 percent). The former is supported by historically high productivity growth while the latter benefits from its relatively high LBIR, as discussed above. The estimated internal rates of return are negative in 13 countries, and exceed the historical average of the S&P 500 return in only 9 countries.

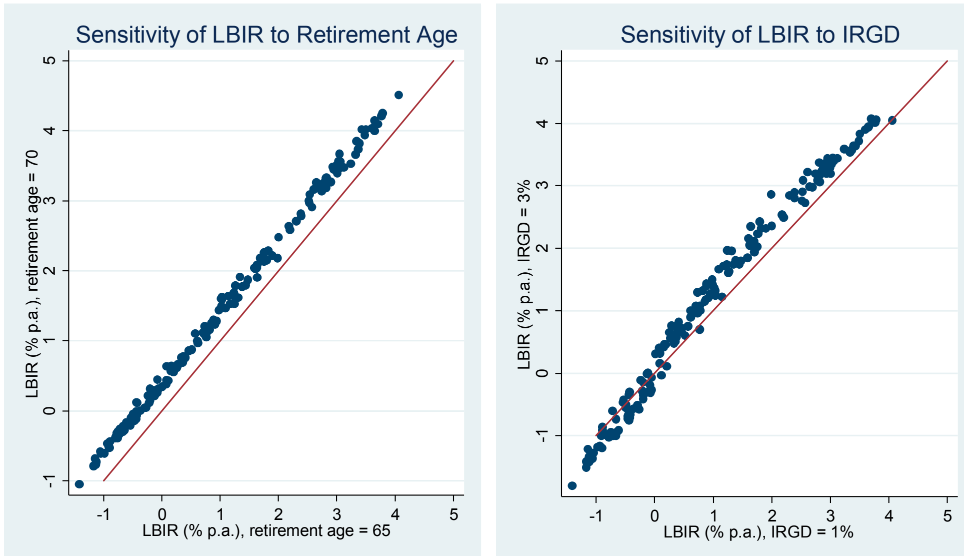
Is the LBIR sensitive to the retirement age and the interest-rate-and-growth differential? The left panel of Figure 4 shows that raising the retirement age from 65 to 70 results in an increase in the LBIR by 40 basis points on average, with the sizes of the increases being similar across countries, regardless of LBIR level. This is substantial, especially for countries with low LBIRs. Nonetheless, the increase in the LBIR (or the internal rate of return) needs to be weighed against longer working years. The right panel of Figure 4 indicates that raising the interest-rate-growth differential does not substantially affect the LBIR; a 200-basis-point increase in the differential, which concomitantly raises the interest rate at which the pension fund can borrow or invest, results in an increase in the LBIR by 20 basis points, on average. The impact tends to be negligible in countries with low LBIRs.

Figure 3. LBIR Plus Productivity Growth by Region
(In percent per year)



Source: Author's calculations.
Note: The box chart plots (1) the LBIR plus historical productivity growth, which is measured by the average growth rate of real GDP per working-age population over 1990–2010, (2) the LBIR only, and (3) the historical productivity growth only. The box chart illustrates the distribution of a variable by showing the maximum and minimum (excluding outliers), the 25th and 75th percentiles (as the boundaries of the box), and the median (the line inside the box). The solid and dotted lines exhibit the average returns of the S&P 500 in real terms, and the U.S. one-year interest rate in real terms for 1970–2010, respectively, from Shiller (2015). Figures in brackets indicate the number of countries.

Figure 4. Sensitivity of LBIR to Retirement Age and the Interest Rate



Source: Author's calculations.
Note: The red line indicates the 45-degree line.

IV. LBIR and Tradeoff Between Pension Contributions and Benefits

In practice, a public pay-as-you-go pension scheme is characterized by the contribution rate and the pension replacement rate (pension benefits divided by pre-retirement wage income). A high replacement rate benefits retirees financially, but it requires a high contribution rate to support the sustainability of the pension system. Nonetheless, a high contribution rate, equivalent to a high tax rate on labor income, discourages labor supply. Therefore, there would be an upper limit for the contribution rate. Raising the retirement age can alleviate this tradeoff by expanding the contribution base and squeezing aggregate pension spending, and is thus deemed effective in preserving the sustainability of a pay-as-you-go pension system (IMF, 2012).

In this section, I analyze the drivers of this tradeoff. A retiree who retires in year $t \geq T_0$ receives a lump-sum pension benefit $\Psi(t)$ (see equation (1)). Suppose she purchases an annuity in year t in exchange for this. Such an annuity pays her $b(t)$ each year until she dies. Let $A_2(t)$ denote remaining life expectancy for individuals retiring in year t (that is, they are expected to live for additional $A_2(t)$ years after retirement). Then, $b(t)$ satisfies:

$$\sum_{s=0}^{A_2(t)} \frac{b(t)}{(1+r)^s} = cW(t) \sum_{k=1}^{A_1-A_0} (1+\phi)^k. \tag{7}$$

Rearranging terms results in

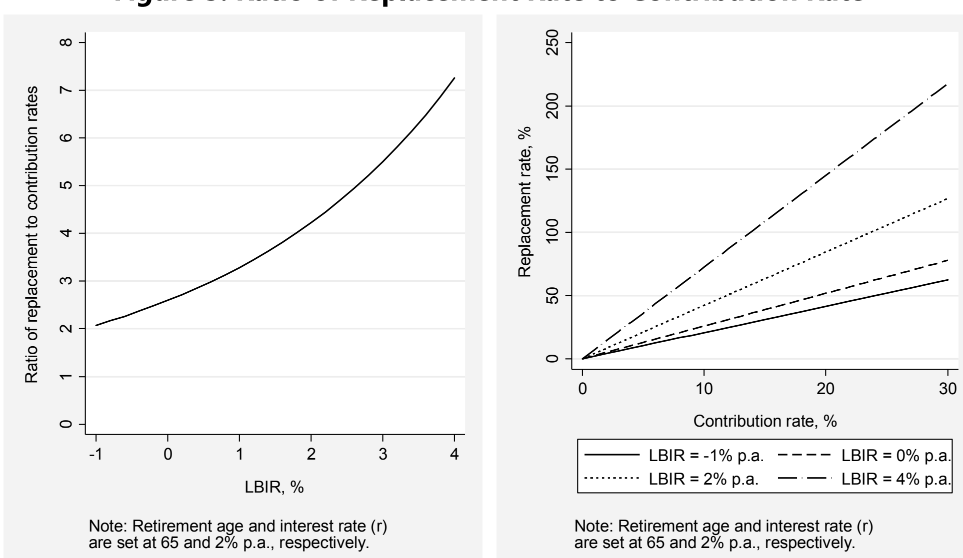
$$\frac{b(t)/W(t)}{c} = \frac{\sum_{s=1}^{A_1-A_0} (1+\phi)^s}{\sum_{s=0}^{A_2(t)} \left(\frac{1}{1+r}\right)^s}. \tag{8}$$

Equation (8) clarifies the tradeoff between the contribution rate (c) and the replacement rate (b/W) for a sustainable pay-as-you-go pension. In what follows, the ratio of the replacement rate to the contribution rate is defined as the Replacement-Contribution Ratio

(RCR). The RCR is a function of the LBIR (ϕ), the interest rate (r), the contribution period ($A_1 - A_0$), and the remaining life expectancy after retirement ($A_2(t)$). A higher LBIR would improve the RCR by boosting the lump sum pension. Similarly, a higher interest rate would improve the RCR by raising the annuity payment as a result of a higher investment return. Raising the retirement age (A_1) would improve the RCR through two channels: (i) increasing the contribution period and reducing the retirement period, and (ii) raising the LBIR as discussed in the previous section. Note that productivity growth (μ) would affect the RCR only through the interest rate (reflecting the fixed interest-rate-growth-differential), because both the wage and lump-sum pension benefits grow in tandem with productivity growth.

The left panel of Figure 5 illustrates the RCR as a function of the LBIR. Here, for an illustrative purpose, the interest rate is assumed at 2 percent per annum, the retirement age at 65, and remaining life expectancy at 20 years. For a country with the LBIR of -1 percent per year, the replacement rate can be only around twice as high as the contribution rate. On the other hand, if the LBIR is as high as 4 percent, the replacement rate can be 7 times as large as the replacement rate. The right panel of Figure 5 shows the replacement rate as a function of the contribution rate for given values of the LBIR. For example, for a country with a LBIR of - 1 percent, achieving a 50 percent replacement rate would require a contribution rate of about 25 percent. A labor tax rate as high as this could significantly distort labor supply. In stark contrast, for a country with a LBIR of 4 percent, a 50 percent replacement rate requires a contribution rate as low as about 7 percent.

Figure 5. Ratio of Replacement Rate to Contribution Rate

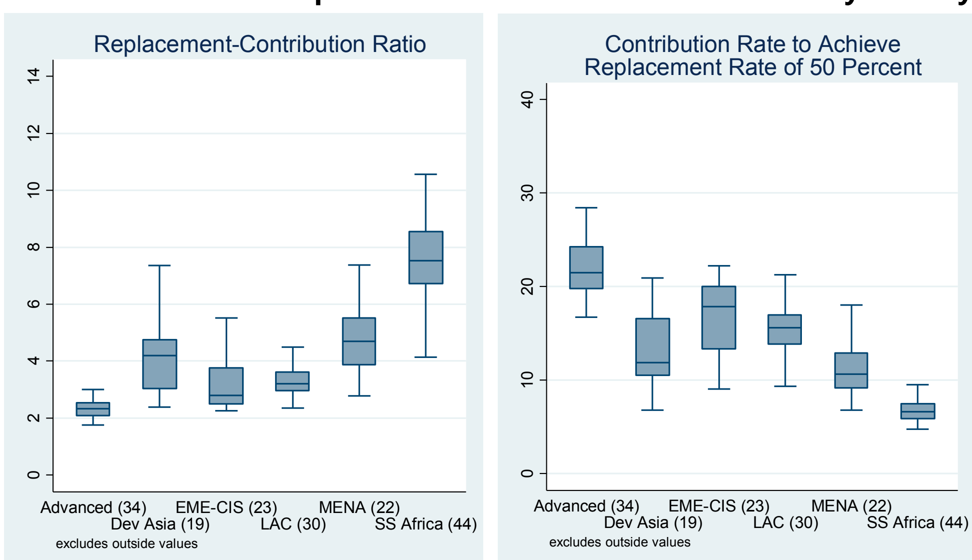


Source: Author's calculations.

Now I present estimates of the RCR by country group (see Appendix II for the RCRs of individual countries). The RCR is calculated from the following parameter values: the real interest rate is assumed at 2 percent per year; the retirement age at 65; the remaining life expectancy as of year 2015; and the interest-rate-growth differential at 1 percent. Figure 6 shows box charts of the RCR (left panel), as well as the contribution rate necessary for a 50 percent replacement rate (right panel). Reflecting the low LBIR, the RCR is particularly low for advanced countries, with the median equal to 2.3. With the median being 21.5 percent, the contribution rate required for a 50 percent replacement rate is relatively high compared with other groups. The RCR is also relatively low for emerging Europe and the CIS (median equal to 2.8) and Latin America and the Caribbean (3.2). On the other hand, the replacement-contribution tradeoff is not a concern for most of the sub-Saharan African countries, whose median RCR is 7.5; the contribution rate required for a 50 percent replacement rate is below 10 percent for most of the countries in this group.

The retirement age has a significant impact on the RCR (Table 3). As noted earlier, a higher retirement age improves the RCR not only by increasing the contribution period and reducing the retirement period, but also by raising the LBIR. Table 3 shows that the median RCR for all countries increases from 3.6 to 5.4 when the retirement age is raised from 65 to 70. This brings down the contribution rate required for a 50 percent replacement rate by about 5 percentage points. This effect is pronounced in advanced countries, which experience a 6.4 percent reduction in the contribution rate required for a 50 percent replacement rate.

Figure 6. Tradeoff Between Replacement Rate and Contribution Rate by Country Group



Source: Author's calculations.
Note: The box charts illustrate the distribution of a variable by showing the maximum and the minimum (excluding outliers), the 25th and 75th percentiles (as the boundaries of the box), and the median (the line inside the box). Figures in brackets indicate the number of countries.

Table 3. Replacement-Contribution Ratio and Required Contribution Rate by Assumption on Retirement Age

	Replacement-Contribution Ratio (median)		Contribution rate required for 50 percent replacement rate (median, %)	
Retirement age	65	70	65	70
All countries	3.6	5.4	13.9	9.2
By country groups				
Advanced	2.3	3.3	21.5	15.0
Emerging Europe and CIS	4.2	6.6	11.9	7.6
Developing Asia	2.8	4.2	17.9	11.9
Latin America and the Caribbean	3.2	4.7	15.6	10.6
Middle East and North Africa	4.7	7.3	10.6	6.9
Sub-Saharan Africa	7.5	13.0	6.6	3.8

Source: Author's calculations.

V. IMPLICATIONS OF DEMOGRAPHIC UNCERTAINTIES

Population projections hinge on long-run demographic assumptions, most notably on fertility, mortality, and migration. Clements and others (2015) highlight substantial uncertainties surrounding these elements, which give rise to substantial fiscal risks connected to age-related public spending on pensions and health care.

In this section, I analyze the implications of demographic uncertainties for the LBIR. I focus on the uncertainties related to fertility. Specifically, I use population projections under low- and high-fertility variants presented by the 2015 UN population projection (United Nations, 2015). The medium-fertility variant of the UN population projection—the basis of the results presented in the previous sections—uses country-specific paths of fertility rates estimated from the latest population survey in each country, as well as the historical evolutions of the fertility rates across countries. Under the low-fertility (high-fertility) variant, the fertility rate is assumed to remain broadly at 0.5 children per woman below (above) the rate envisaged under the medium-fertility variant. I do not analyze uncertainties related to mortality or migration because the UN population projection does not provide alternative variants to treat them in symmetrical settings.[8]

The low- and high-fertility variants would represent extreme cases for most countries except sub-Saharan Africa. The UN projection produces a probability distribution of the fertility rate for each country over the long run, based on 60,000 trajectories of the fertility rate generated by simulations. For advanced countries, the paths of the fertility rate under the low- and high-fertility variants lie outside the 80th percentile band in 33 out of the 34 countries in the sample, and outside the 95th percentile band in 22 countries. This is illustrated by the example of the United States, as shown in the left panel of Figure 7. Also, in 85 out of 94 developing

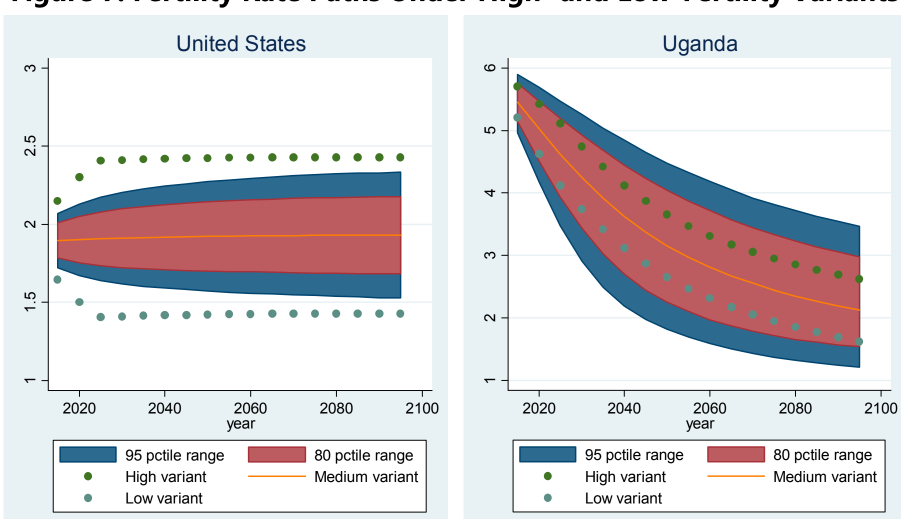
[8] The UN projection only includes variants with constant mortality (the mortality rate kept constant at the 2010–2015 level) and zero migration.

countries except sub-Saharan African countries, the paths of the fertility rates under the low- and high-fertility variants lie outside the 80th percentile band. Sub-Saharan Africa is an exception, as the paths lie outside the 80th percentile band in only 10 countries out of the 44 countries in the sample. In the right panel of Figure 7, Uganda is shown as an example where the paths under low- and high-fertility variants lie well inside the 80th percentile band.

The results reported in Table 4 and Figure 8 show the implications of low and high fertility rates. Here, the retirement age and the interest-rate-growth-differential are set at 65 and 1 percent, respectively. On average, the LBIR is 0.6 (0.4) percentage points lower (higher) under the low (high) fertility variant than under the medium-fertility variant (the base case). Under the low-fertility variant, the LBIR is negative for most of the advanced countries and three-fourths of the countries in emerging Europe and the CIS, and less than 1 percent for three-fourths of the countries in developing Asia as well as Latin America and the Caribbean. Most of the countries in sub-Saharan Africa have relatively high LBIRs even under the low-fertility variant, with the median being 2.7 percent. Nevertheless, as discussed above, the path of the fertility rate under the low- or the high-fertility variant does not generally represent an extreme event in sub-Saharan Africa.

Table 4 shows that the median RCR is about 0.4 lower (higher) under the low-fertility (high-fertility) variant than under the medium-fertility variant. The contribution rate required for a 50 percent replacement rate is 1.9 (1.4) percentage points higher under the low-fertility variant than under the medium-fertility variant. The risk of low fertility is substantial in advanced countries, where the median contribution rate needed to achieve a 50 percent replacement rate is 23 percent under the low-fertility variant. On the other hand, the contribution-replacement tradeoff is much less pronounced for sub-Saharan Africa, where the contribution rate of 7.2 percent can still achieve a 50 percent replacement rate under the low-fertility variant.

Figure 7. Fertility Rate Paths Under High- and Low-Fertility Variants



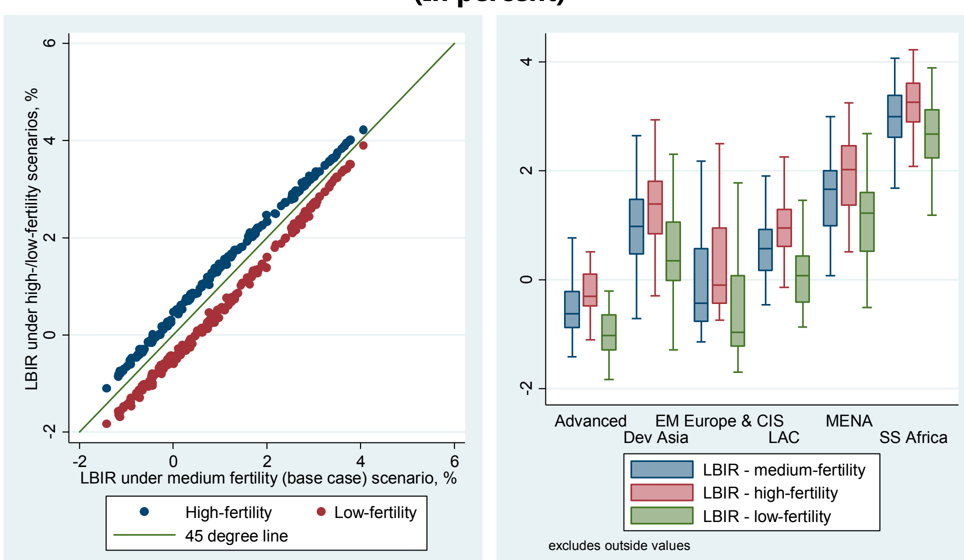
Source: 2015 Revision of the United Nations World Population Prospects (United Nations, 2015).
Note: The UN projection produces a probability distribution of the fertility rate over the long run, based on 60,000 trajectories of fertility rates generated by model simulations. The fan charts exhibits this distribution by showing the 80th percentile and 95th percentile bands. The fertility rate paths assumed under the medium-, high-, and low-variants are also shown.

Table 4. Impact of Fertility Rate Assumptions on LBIR and Tradeoff Between Contribution and Replacement Rates

	Long-Run Biological Interest Rate (LBIR) (median, %)			Replacement-Contribution Ratio (RCR) (median)			Contribution rate for 50% replacement rate (median, %)			Number of countries
	Medium fertility	Low fertility	High fertility	Medium fertility	Low fertility	High fertility	Medium fertility	Low fertility	High fertility	
All countries	0.9	0.3	1.3	3.6	3.2	4.0	13.9	15.8	12.5	172
	(1.5)	(1.5)	(1.4)	(2.3)	(2.1)	(2.4)	(6.0)	(6.6)	(5.6)	
By country group										
Advanced	-0.6	-1.0	-0.3	2.3	2.1	2.5	21.5	23.4	20.1	34
	(0.5)	(0.5)	(0.4)	(0.3)	(0.3)	(0.3)	(2.6)	(2.9)	(2.4)	
Emerging Europe and CIS	-0.4	-1.0	-0.1	2.8	2.5	3.0	17.9	19.9	16.4	23
	(1.0)	(1.0)	(1.0)	(1.0)	(0.9)	(1.1)	(4.0)	(4.5)	(3.8)	
Developing Asia	1.0	0.3	1.4	4.2	3.6	4.6	11.9	13.9	10.8	19
	(0.9)	(0.9)	(0.9)	(1.3)	(1.2)	(1.4)	(3.7)	(4.3)	(3.4)	
Latin America and the Caribbean	0.6	0.1	1.0	3.2	2.8	3.5	15.6	17.6	14.1	30
	(0.6)	(0.6)	(0.6)	(0.7)	(0.6)	(0.8)	(2.7)	(3.1)	(2.5)	
Middle East and North Africa	1.7	1.2	2.0	4.7	4.1	5.2	10.6	12.1	9.6	22
	(0.8)	(0.9)	(0.8)	(1.4)	(1.3)	(1.5)	(3.0)	(3.5)	(2.7)	
Sub-Saharan Africa	3.0	2.7	3.3	7.5	6.9	8.2	6.6	7.2	6.1	44
	(0.9)	(0.9)	(0.8)	(1.7)	(1.7)	(1.8)	(2.5)	(3.0)	(2.3)	

Source: Author's calculations.
Note: Figures in brackets indicate standard deviation.

Figure 8. Estimates of LBIR Under High- and Low-Fertility Scenarios (In percent)



Source: Author's calculations.
Note: The box chart in the right panel illustrates the distribution of a variable by showing the maximum and minimum (excluding outliers), the 25th and 75th percentiles (as the boundaries of the box), and the median (the line inside the box).

VI. CONCLUDING REMARKS AND POLICY IMPLICATIONS

In many countries, actuarial studies are conducted periodically to analyze whether the public pension schemes satisfy the long-run budget constraints. If an actuarial study finds that the pension scheme is unsustainable, parametric pension reforms would become necessary. Broadly speaking, the menu of policy options for regaining sustainability consists of raising the contribution rate, cutting pension benefits, and/or raising the retirement age.

Here, note that the long-run budget constraint would not be sufficient to ensure incentive compatibility, that is, the pension scheme offers an internal rate of return adequate for the working-age population to opt for the scheme. The parametric pension reforms may require some generations (typically those who are not born yet) to accommodate an internal rate of return much lower than those offered by alternative investment options. If this is the case, it would be unrealistic to assume in an actuarial study that the pension scheme would achieve the full participation of eligible individuals. In this context, this paper addresses the incentive compatibility problem by computing the internal rate of return for a pay-as-you-go pension scheme created in 2015, to be sustained through 2100.

This paper finds that the internal rate of return for such a pay-as-you-go scheme is the sum of the LBIR and productivity growth. The LBIR estimates across countries indicate that LBIRs are globally low—the median LBIR for 172 countries is only 0.9 percent per year. Demographic risks are significant—a lower-than-envisaged fertility rate in the future would lead to a LBIR that is lower by about 60 basis points on average. This suggests that sustaining the incentive compatibility for a pay-as-you-go pension scheme hinges on ample productivity growth in the future in many countries.

To end on a positive note, raising the retirement age is a viable option to ratchet up the LBIR. Raising the retirement age by five years (from 65 to 70) increases the LBIR in all countries by about 40 basis points on average. Raising the retirement age would improve the tradeoff between the contribution rate and the replacement rate not only by increasing contribution periods and reducing retirement periods, but also by raising the LBIR. This reinforces the argument for raising the retirement age as a more viable option than raising the contribution rate or cutting pension benefits.

Finally, it is worth noting that my approach is much simpler than the traditional approaches that are based on actuarial studies. In particular, calculating the LBIR does not require any knowledge of a country's pension system, thereby dramatically reducing data and information requirements. Further, by focusing on a uniform internal rate of return for current and future generations, my approach takes account of the long-run budget constraint as well as intergenerational equity. It also presents a simple framework by which to analyze parametric reform options by representing the tradeoff between the contribution rate and the replacement rate as a function of the LBIR and the retirement age. Finally, the LBIR and the RCR augment the list of cross-country indicators to analyze pension sustainability.

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Appendix I. Composition of Country Groups by Income and Region

Advanced

Australia
Austria
Belgium
Canada
Cyprus
Czech Republic
Denmark
Estonia
Finland
France
Germany
Greece
Hong Kong
Iceland
Ireland
Israel
Italy
Japan
Korea, Republic of
Latvia
Lithuania
Luxembourg
Netherlands
New Zealand
Norway
Portugal
Singapore
Slovak Republic
Slovenia
Spain
Sweden
Switzerland
United Kingdom
United States

Middle income

Emerging Europe and CIS

Albania
Armenia
Azerbaijan, Rep. of
Belarus
Bosnia & Herzegovina
Bulgaria
Croatia
Georgia
Hungary
Kazakhstan
Macedonia, FYR
Montenegro
Poland
Romania
Russian Federation
Serbia, Republic of
Turkey
Turkmenistan
Ukraine

Developing Asia

Brunei Darussalam
China, Mainland
India
Indonesia
Malaysia
Maldives
Philippines
Sri Lanka
Thailand
Timor-Leste

Latin America and the Caribbean

Antigua and Barbuda
Argentina
Bahamas, The
Barbados
Belize
Brazil
Chile
Colombia
Costa Rica
Dominican Republic
Ecuador
El Salvador
Grenada
Guatemala
Guyana
Jamaica
Mexico
Panama
Paraguay
Peru
St. Lucia
St. Vincent & Grens.
Suriname
Trinidad and Tobago
Uruguay
Venezuela, Rep. Bol.

Middle East and North Africa

Algeria
Bahrain, Kingdom of
Egypt
Iran, I.R. of
Iraq
Jordan
Kuwait
Lebanon
Libya
Morocco
Oman
Pakistan
Qatar
Saudi Arabia
Syrian Arab Republic
Tunisia
United Arab Emirates

Sub-Saharan Africa

Angola
Botswana
Cape Verde
Equatorial Guinea
Gabon
Mauritius
Namibia
Seychelles
South Africa
Swaziland

Low income

Emerging Europe and CIS

Kyrgyz Republic
Moldova
Tajikistan
Uzbekistan

Developing Asia

Bangladesh
Bhutan
Cambodia
Lao People's Dem. Rep.
Mongolia
Myanmar
Nepal
Papua New Guinea
Vietnam

Latin America and the Caribbean

Bolivia
Haiti
Honduras
Nicaragua

Middle East and North Africa

Afghanistan, I.R. of
Djibouti
Mauritania
Sudan
Yemen, Republic of

Sub-Saharan Africa

Benin
Burkina Faso
Burundi
Cameroon
Central African Rep.
Chad
Comoros
Congo, Dem. Rep. of
Congo, Republic of
Cote d'Ivoire
Eritrea
Ethiopia
Gambia, The
Ghana
Guinea
Guinea-Bissau
Kenya
Lesotho
Liberia
Madagascar
Malawi
Mali
Mozambique
Niger
Nigeria
Rwanda
Sao Tome & Principe
Senegal
Sierra Leone
Tanzania
Togo
Uganda
Zambia
Zimbabwe

Source: Author’s Calculations

Appendix II. Estimated Long-Run Biological Interest Rate and Demographic Indicators by Country

Country	Long-Run Biological Interest Rate (LBIR)	Replacement-Contribution Ratio (RCR)	Contribution rate required for 50% replacement rate	Dependency ratio in 2015 (%) 1/	Dependency ratio in 2100 (%) 1/	Working-age population growth rate (%, age 20-64)
Advanced						
Australia	0.1	2.5	19.6	25.1	58.6	0.5
Austria	-0.8	2.2	23.2	30.4	67.2	-0.3
Belgium	-0.5	2.3	21.6	30.7	60.1	0.0
Canada	-0.4	2.3	21.8	26.0	61.6	0.1
China, Hong Kong	-0.8	2.0	24.9	22.1	69.1	-0.3
Cyprus	-0.2	2.6	19.0	20.0	63.8	-0.1
Czech Republic	-0.8	2.3	21.4	28.9	59.5	-0.5
Denmark	-0.4	2.4	20.7	32.8	58.1	0.1
Estonia	-0.7	2.4	21.1	30.8	58.3	-0.7
Finland	-0.7	2.2	22.6	35.5	62.6	-0.1
France	-0.4	2.2	22.7	33.8	62.1	0.0
Germany	-1.1	2.0	24.6	34.9	71.0	-0.6
Greece	-1.1	2.0	24.8	36.1	72.6	-0.7
Iceland	-0.2	2.4	20.9	23.1	68.6	-0.1
Ireland	-0.1	2.6	19.5	22.1	59.1	0.1
Israel	0.8	3.0	16.7	21.1	54.4	0.8
Italy	-1.2	1.9	26.4	37.9	72.5	-0.5
Japan	-1.4	1.8	28.4	47.0	76.1	-0.7
Korea, Republic of	-0.9	2.1	24.3	19.8	78.3	-0.7
Latvia	-0.7	2.6	19.6	31.4	51.5	-0.7
Lithuania	-0.6	2.7	18.6	30.9	50.1	-0.6
Luxembourg	0.2	2.7	18.7	22.0	56.6	0.5
Netherlands	-0.6	2.2	22.3	30.7	63.2	-0.2
New Zealand	-0.2	2.4	20.8	25.6	65.0	0.1
Norway	-0.1	2.5	20.0	27.5	57.4	0.3
Portugal	-1.2	2.0	25.2	34.7	75.1	-0.7
Singapore	-0.9	2.0	25.0	17.6	89.4	-0.4
Slovak Republic	-0.7	2.5	19.7	21.0	60.1	-0.7
Slovenia	-0.9	2.1	23.3	28.6	63.4	-0.5
Spain	-1.0	2.0	25.1	30.4	71.4	-0.5
Sweden	-0.3	2.4	21.0	34.6	56.3	0.3
Switzerland	-0.5	2.2	22.5	29.1	62.8	0.1
United Kingdom	-0.3	2.4	20.5	30.3	59.2	0.1
United States	-0.1	2.6	19.4	24.7	53.1	0.2
Emerging Europe and CIS						
Albania	-0.5	2.5	19.8	20.6	80.3	-0.9
Armenia	-0.4	2.7	18.3	16.7	65.7	-0.9
Azerbaijan, Rep. of	0.6	3.8	13.3	8.6	43.9	-0.2
Belarus	-0.2	3.1	16.3	21.4	43.7	-0.6
Bosnia & Herzegovina	-1.1	2.3	21.7	23.7	71.0	-1.2
Bulgaria	-1.1	2.5	20.4	32.6	54.5	-1.1
Croatia	-1.0	2.3	21.8	31.3	67.6	-0.8
Georgia	-0.5	2.7	18.4	22.4	61.7	-0.8
Hungary	-0.7	2.5	20.0	28.5	57.2	-0.7
Kazakhstan	1.1	4.5	11.0	11.2	36.7	0.3
Kyrgyz Republic	1.6	4.9	10.2	7.6	37.9	0.5
Macedonia, FYR	-0.5	2.8	17.9	19.2	61.9	-0.7

Source: Author's calculations.

1/ Population aged 65+ as percent of population aged 20-64.

Appendix II. *(continued)*

Country	Long-Run Biological Interest Rate (LBIR)	Replacement-Contribution Ratio (RCR)	Contribution rate required for 50% replacement rate	Dependency ratio in 2015 (%) 1/	Dependency ratio in 2100 (%) 1/	Working-age population growth rate (%, age 20-64)
Moldova	-0.4	3.1	16.3	14.6	52.6	-1.2
Montenegro	-0.5	2.7	18.4	22.4	61.1	-0.6
Poland	-0.9	2.2	22.2	24.1	70.0	-1.0
Romania	-0.9	2.4	20.4	28.0	59.3	-0.9
Russian Federation	-0.1	3.1	15.9	20.4	39.6	-0.4
Serbia, Republic of	-0.8	2.6	19.1	28.3	61.3	-0.8
Tajikistan	2.2	5.5	9.1	5.8	34.0	1.1
Turkey	0.4	3.2	15.8	12.9	64.3	0.0
Turkmenistan	1.3	4.8	10.5	7.1	37.4	0.0
Ukraine	-0.4	3.0	16.9	23.5	41.3	-0.8
Uzbekistan	1.3	4.4	11.5	8.0	40.2	0.1
Developing Asia						
Bangladesh	1.0	3.9	12.9	9.0	62.2	0.0
Bhutan	0.9	3.6	14.0	8.6	63.9	-0.1
Brunei Darussalam	0.3	3.0	16.6	6.9	70.3	-0.1
Cambodia	1.4	4.8	10.5	7.6	53.2	0.5
China, Mainland	-0.5	2.7	18.4	14.2	70.2	-0.8
India	1.0	4.2	11.9	10.0	53.4	0.2
Indonesia	1.0	4.6	11.0	8.9	41.0	0.2
Lao People's Dem. Rep.	1.6	5.2	9.6	7.6	53.7	0.6
Malaysia	0.7	3.7	13.7	9.7	57.0	0.2
Maldives	0.7	3.6	13.9	8.0	65.6	0.0
Mongolia	1.5	4.4	11.3	6.7	50.5	0.3
Myanmar	1.0	4.5	11.0	9.3	38.0	0.0
Nepal	0.9	4.2	11.9	11.0	68.6	0.0
Papua New Guinea	2.6	7.4	6.8	6.1	25.6	1.2
Philippines	1.7	5.3	9.4	8.6	35.2	0.7
Sri Lanka	-0.1	2.8	17.6	15.9	69.5	-0.6
Thailand	-0.7	2.4	20.9	16.0	71.6	-0.9
Timor-Leste	2.6	6.6	7.6	13.5	31.8	1.6
Vietnam	0.5	3.0	16.6	10.7	57.4	-0.1
Latin America and the Caribbean						
Antigua and Barbuda	0.5	3.1	15.9	11.9	57.7	0.1
Argentina	0.5	3.2	15.8	19.5	57.0	0.2
Bahamas, The	0.4	2.9	17.0	13.2	58.1	0.1
Barbados	-0.5	2.8	18.1	23.6	59.0	-0.3
Belize	1.8	5.4	9.3	7.1	41.0	0.8
Bolivia	1.4	4.0	12.5	12.7	47.9	0.7
Brazil	0.2	2.9	17.2	12.9	68.0	-0.3
Chile	-0.1	2.3	21.3	17.9	74.8	-0.2
Colombia	0.3	3.0	16.7	11.7	65.3	-0.3
Costa Rica	0.1	2.6	19.0	14.7	70.3	-0.2
Dominican Republic	0.9	3.4	14.8	12.3	59.7	0.1
Ecuador	0.9	3.3	15.2	12.2	60.7	0.4
El Salvador	0.4	3.0	16.5	15.0	75.5	-0.5
Grenada	0.4	3.5	14.4	12.5	70.8	-0.6
Guatemala	1.9	4.5	11.1	10.2	46.6	1.1
Guyana	1.0	4.7	10.6	9.3	41.9	-0.2
Haiti	1.6	4.9	10.1	9.1	42.2	0.4

Source: Author's calculations.

1/ Population aged 65+ as percent of population aged 20-64.

Appendix II. *(continued)*

Country	Long-Run Biological Interest Rate (LBIR)	Replacement-Contribution Ratio (RCR)	Contribution rate required for 50% replacement rate	Dependency ratio in 2015 (%) 1/	Dependency ratio in 2100 (%) 1/	Working-age population growth rate (%, age 20-64)
Honduras	1.2	3.6	13.8	9.3	61.8	0.3
Jamaica	0.0	2.8	18.1	15.9	76.8	-0.8
Mexico	0.6	3.1	16.3	11.4	70.7	0.0
Nicaragua	0.8	3.2	15.4	9.3	70.9	0.0
Panama	0.8	3.1	16.4	13.5	58.1	0.4
Paraguay	1.3	3.9	12.9	11.2	49.8	0.3
Peru	0.8	3.4	14.9	12.1	63.7	0.2
St. Lucia	0.2	2.9	17.1	15.2	66.4	-0.3
St. Vincent & Grens.	0.2	3.1	15.9	12.4	64.0	-0.6
Suriname	0.7	3.8	13.1	12.0	50.5	-0.1
Trinidad and Tobago	0.1	3.3	15.0	14.8	46.5	-0.6
Uruguay	-0.1	2.7	18.5	25.5	62.8	-0.2
Venezuela, Rep. Bol.	0.9	3.5	14.3	11.1	57.5	0.2
Middle East and North Africa						
Afghanistan, I.R. of	2.6	7.1	7.1	5.9	34.2	1.1
Algeria	0.9	3.5	14.3	10.2	55.9	0.4
Bahrain, Kingdom of	1.3	4.2	11.8	3.5	54.9	-0.1
Djibouti	1.7	5.1	9.8	7.9	37.3	0.4
Egypt	1.7	5.2	9.7	9.8	39.5	1.0
Iran, I.R. of	0.3	3.3	15.0	7.9	60.3	-0.4
Iraq	3.0	7.2	6.9	6.7	24.3	2.1
Jordan	1.8	4.8	10.4	7.5	47.3	0.8
Kuwait	1.8	5.3	9.4	2.8	43.2	0.4
Lebanon	0.1	2.8	18.0	13.9	76.6	-0.5
Libya	1.0	4.2	12.0	7.9	51.1	0.2
Mauritania	2.8	7.4	6.8	6.9	21.5	1.7
Morocco	0.6	3.6	13.9	10.6	60.1	0.1
Oman	1.2	3.9	12.9	3.6	64.3	0.0
Pakistan	2.0	5.5	9.1	8.9	35.1	1.0
Qatar	2.0	4.7	10.7	1.5	53.6	0.0
Saudi Arabia	1.2	4.3	11.6	4.7	51.4	0.4
Sudan	2.8	6.7	7.4	7.3	25.0	1.7
Syrian Arab Republic	1.6	4.7	10.5	8.6	49.9	1.0
Tunisia	0.4	3.3	14.9	12.3	56.2	-0.1
United Arab Emirates	1.6	4.4	11.3	1.4	50.6	0.0
Yemen, Republic of	2.5	6.8	7.3	6.1	34.1	1.1
Sub-Saharan Africa						
Angola	3.8	9.7	5.2	5.9	19.8	2.5
Benin	3.0	8.1	6.1	6.5	21.9	1.8
Botswana	1.8	5.4	9.3	6.6	39.5	0.6
Burkina Faso	3.5	9.5	5.3	5.8	20.6	2.2
Burundi	3.5	8.6	5.8	5.8	20.2	2.4
Cameroon	3.1	7.6	6.6	7.4	26.1	1.8
Cape Verde	1.1	4.1	12.1	8.3	61.9	0.2
Central African Rep.	2.5	6.8	7.3	8.3	32.4	1.4
Chad	3.8	9.8	5.1	6.3	20.4	2.4
Comoros	2.8	7.3	6.8	6.0	26.7	1.5
Congo, Dem. Rep. of	3.4	8.3	6.0	7.3	23.1	2.4

Source: Author's calculations.

1/ Population aged 65+ as percent of population aged 20-64.

Appendix II. *(concluded)*

Country	Long-Run Biological Interest Rate (LBIR)	Replacement-Contribution Ratio (RCR)	Contribution rate required for 50% replacement rate	Dependency ratio in 2015 (%) 1/	Dependency ratio in 2100 (%) 1/	Working-age population growth rate (%, age 20-64)
Congo, Republic of	3.0	7.0	7.1	8.4	23.9	2.2
Côte d'Ivoire	3.3	9.4	5.3	7.0	20.7	2.1
Equatorial Guinea	2.5	6.5	7.7	6.0	32.4	1.7
Eritrea	3.0	7.7	6.5	5.9	30.1	1.6
Ethiopia	2.4	6.0	8.4	8.1	41.4	1.4
Gabon	2.2	5.6	8.9	10.7	34.5	1.3
Gambia, The	3.7	9.8	5.1	5.7	19.4	2.2
Ghana	2.7	7.5	6.7	7.1	23.0	1.4
Guinea	3.0	8.2	6.1	7.0	26.9	1.9
Guinea-Bissau	2.9	8.2	6.1	7.0	21.3	1.6
Kenya	2.9	6.9	7.3	6.2	29.2	1.8
Lesotho	2.7	7.3	6.8	8.6	31.6	0.8
Liberia	3.0	8.2	6.1	6.8	23.4	1.8
Madagascar	3.0	7.4	6.7	6.4	26.8	2.0
Malawi	3.2	7.2	6.9	8.5	26.4	2.3
Mali	3.6	9.7	5.2	6.4	23.7	2.4
Mauritius	-0.2	2.8	18.0	15.1	63.7	-0.6
Mozambique	3.4	8.1	6.2	8.3	23.5	2.2
Namibia	2.4	6.2	8.1	7.2	34.0	1.2
Niger	4.1	10.6	4.7	7.0	15.5	3.3
Nigeria	3.4	10.1	4.9	6.4	18.3	2.1
Rwanda	2.3	5.8	8.6	6.1	42.7	1.2
Sao Tome & Principe	2.9	6.7	7.4	7.1	26.0	1.6
Senegal	3.1	7.8	6.4	6.8	28.0	2.2
Seychelles	0.3	3.3	15.2	10.9	55.4	-0.4
Sierra Leone	3.0	9.4	5.3	6.0	23.0	1.3
South Africa	1.7	5.3	9.5	9.0	38.8	0.2
Swaziland	2.9	7.5	6.7	7.5	31.3	0.8
Tanzania	3.3	7.4	6.7	7.8	23.6	2.4
Togo	3.1	8.4	6.0	6.2	23.9	1.9
Uganda	3.7	8.8	5.7	6.5	22.7	2.5
Zambia	3.7	8.4	5.9	7.2	20.3	2.6
Zimbabwe	2.8	6.7	7.5	6.6	34.2	1.4

Source: Author's calculations.

1/ Population aged 65+ as percent of population aged 20-64.