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Aging on a Short Clock: Demographic Compression, Fiscal Adjustment, and Growth*

Selahattin İmrohoroglu[†]

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Abstract

Population aging is usually summarized by a single number—an old-age dependency ratio (OADR), or a projected drag on growth—as though fiscal pressure and growth pressure were two readings of the same quantity. Using the 2024 UN World Population Prospects and Penn World Table 11.0, this paper measures both on a common basis for 103 economies and finds that they are not. The speed through the critical range, in which four working-age adults per elderly person become two, strongly predicts the required retirement-age adjustment ($\rho = -0.69$) but is nearly unrelated to the demographic growth effect in a calibrated Solow decomposition ($\rho = 0.14$).

The two measures differ because one compares age structures at two dates whereas the other depends on the path between them and on how much calendar time it occupies. The dissociation survives finer partitions of the transition, a projection truncated at 2060, alternative working-age boundaries, and either allocation of the interaction between the two channels; it attenuates only among economies that traverse the entire transition within the projection window.

The first implication is for measurement: projected growth drag is not a sufficient statistic for fiscal urgency, so rankings built on either measure alone misidentify which economies face the hardest adjustment.

The second is sharper. Higher fertility moves only the denominator of OADR, with a lag of at least two decades, and in the interim raises the total dependency ratio: under the UN’s medium variant Korea has a *higher* total dependency ratio in 2050 than under the low variant, and a smaller working-age share until 2060. The retirees of the next two to three decades are already alive, so the initial phase of the adjustment is locked in by today’s age structure regardless of future fertility.

Keywords: Population aging, dependency ratios, retirement age, growth drag, demographic compression.

JEL Codes: E62, H55, J11, J26

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1 Introduction

How hard an economy’s aging problem is depends on what one measures. A country with a high old-age dependency ratio, the number of individuals 65 and older divided by the number of individuals between 20 and 64, is often described as facing severe demographic pressure; so is one whose projected growth is most reduced by a shrinking working-age share. These are usually treated as alternative readings of the same underlying difficulty. This paper measures both on a common basis for 103 economies and shows that they are distinct, that they frequently disagree, and that the disagreement is systematic. The sample contains 34 early-aging and 69 late-aging economies, classified by whether their 2024 OADR exceeds 30 percent.¹

The central result can be stated in two correlations. The speed with which an economy crosses the range from an OADR of 25 percent to 50 percent—from four working-age adults per elderly person to two—strongly predicts the scale of the retirement-age adjustment required to hold its support ratio fixed ($\rho = -0.69$). The same speed measure is nearly unrelated to the demographic growth effect implied by a calibrated Solow growth decomposition ($\rho = 0.14$). An economy can therefore face acute fiscal pressure without an unusual growth headwind, or a large growth headwind without the compressed adjustment window that makes pension reform politically hard.

The two measures separate because they are different kinds of objects. The retirement-boundary statistic compares two age structures at two dates; it is an endpoint comparison, and it is large when the endpoint is far from the starting point. The demographic growth effect depends on the entire path of working-age shares between those dates, and on how many years that path occupies—a decline spread over sixty years and the same decline compressed into fifteen have very different implications for the fiscal adjustment and nearly identical implications for average growth. Germany and Sweden take 60 and 80 years respectively to traverse the 25–50 percent range; Korea is projected to take 14 years and China 18. Japan took 19—as compressed as either, but between 1997 and 2016, so that its adjustment window has already closed while Korea’s is open now and China’s opens in 2028. Endpoint dependency ratios conceal both differences. Endpoint dependency ratios conceal this difference entirely. I call it *demographic compression*: the extent to which the calendar time available to move between two dependency thresholds is shorter for one economy than for another. Compression is a statement about duration, not about level. An economy may be highly compressed and still comparatively young today, and two economies reaching the same OADR in 2100 may have had very different amounts of time in which to prepare.

Establishing the dissociation requires three measurement steps, and these constitute the paper’s methodological contribution. First, I record the time each economy takes to cross OADR thresholds of 12.5, 25, 50, and 100 percent, which makes compression directly comparable across countries. Second, I compute a demographically equivalent retirement boundary: the age cutoff in 2100 that would reproduce each country’s 2024 OADR. This is an age-structure accounting equivalent, not a feasible policy recommendation—it treats all persons below the boundary as potential supporters and abstracts from health, productivity, participation, and behavioral response. Extreme implied ages are evidence that

¹Using 28 or 32 percent as the sample defining OADR yields nearly identical results.

retirement-age policy alone cannot stabilize the support ratio, and they summarize the scale of adjustment that must instead be divided among later retirement, lower benefits, higher contributions, broader taxation, greater participation, and immigration. Third, I place the same demographic projections inside a calibrated Solow growth model with working-age population as the labor input, and use a Shapley decomposition to separate the contribution of the changing working-age share from that of convergence in country-specific TFP growth. The decomposition is exact: the two components sum to total drag by construction.

The dissociation survives several robustness checks. It does not depend on where the transition is partitioned: splitting the upper range at an OADR of 75 percent yields correlations with the required retirement-boundary increase of -0.84 and -0.52 on the 50–75 and 75–100 segments, against correlations with the demographic growth effect of $+0.32$ and $+0.20$. It does not depend on the length of the projection window: truncating at 2060, so that the projected working-age population consists almost entirely of cohorts already born, leaves the speed–drag correlation at -0.07 , while the demographic drag itself correlates at 0.95 across the two horizons. It does not depend on the working-age boundary, on the Chinese GDP series, or on the equal-weighting convention in the Shapley allocation, where the interaction between the two channels never exceeds 0.07 percentage points and no component changes sign under either ordering.

The one systematic exception is informative. Among the 36 economies that traverse the entire transition within the projection window of 2100, the speed–drag correlation rises from $+0.14$ to $+0.31$, and fiscal urgency and growth pressure move together. This is the same compositional pattern that appears in the within-group correlations between drag and required adjustment, which are strong within the early-aging and late-aging groups separately (-0.89 and -0.79) but much weaker when pooled (-0.49). The claim of this paper is therefore not that fiscal and growth pressure are unrelated. It is that they do not coincide across the full cross section of aging economies, because economies at different stages of the transition sit differently in the two dimensions—and that a ranking built on either measure alone will misidentify which economies face the hardest adjustment.

It should be emphasized that none of the adjustment margins listed above is fertility. Everyone aged 65 or over in 2090 was born by 2025, so the numerator of the old-age dependency ratio is already determined for the remainder of the century in every economy studied here. Higher fertility from today can move only the denominator, and does so with a lag of at least two decades; in the interim it raises the total dependency ratio, because additional children are dependents before they are workers. Under the UN’s medium variant Korea has a *higher* total dependency ratio in 2050 than under the low variant, and a smaller working-age share until 2060. Section 3.7 quantifies both effects. The point is not that family policy is unwarranted—it has an independent justification in helping households achieve their desired family size—but that the adjustment documented here must be financed by cohorts already alive.

Two features of the exercise should be stated at the outset. The paper does not estimate behavioral elasticities or solve a country-specific calibrated overlapping generations model to examine pension reform. It constructs transparent cross-country accounting benchmarks that any richer structural analysis must confront, and its comparability across 103 economies is bought precisely by that simplicity. The main text uses the WPP 2024 low-fertility variant as the baseline. Recent fertility outcomes in most economies make

this the disciplined choice rather than a pessimistic one: Japan recorded 686,061 births in 2024, China’s total fertility rate fell to roughly 1.0 in 2023, and Korea’s to 0.68 in 2024, all tracking the low variant more closely than the rebound embedded in the medium path. Appendix B compares the variants against independent projections; the medium variant is reported throughout as a sensitivity.

The paper proceeds as follows. Section 2 reviews related literature. Section 3 documents OADR trajectories, aging speed, required retirement-age adjustments, and the limits of fertility policy. Section 4 develops the Solow model and the Shapley decomposition and establishes the central dissociation. Section 5 subjects it to four checks: the working-age definition, the Chinese GDP series, the length of the projection horizon, and the weighting of the Shapley allocation. Section 6 concludes.

2 Related Literature

This paper connects four strands of research on demographic aging, public pensions, and long-run growth, but differs from much of the existing literature by using a deliberately simple cross-country accounting framework rather than a country-specific structural pension model.

The first strand studies pension reform and fiscal sustainability in overlapping-generations models. Auerbach and Kotlikoff (1987) develop the benchmark multi-cohort framework linking demographic change, capital accumulation, and government budgets in general equilibrium. Huang, Imrohoroglu, and Sargent (1997), Kotlikoff (1997), Kotlikoff, Smetters, and Walliser (1999), and De Nardi, Imrohoroglu, and Sargent (1999) use large-scale OLG models to evaluate Social Security reforms and the transition costs of moving from pay-as-you-go to more funded systems. These studies show that demographic change creates large implicit liabilities and that reforms with similar long-run effects can have very different transitional welfare consequences across cohorts. Unlike that literature, this paper abstracts from behavioral responses and distributional consequences within countries in order to provide a unified set of cross-country benchmarks. Instead of building a structural pension model for each country, I use a simple cross-country statistic—the demographically equivalent retirement boundary that reproduces the 2024 OADR—to compare the magnitude of demographic pressure across many economies.

A second strand studies automatic stabilizers and institutional design in pension systems. Nonfinancial defined contribution systems, sustainability factors, and demographic indexation rules adjust benefits or contributions in response to longevity, wage growth, or contributor-beneficiary ratios; Holzmann, Palmer, and Robalino (2017) provides a broad discussion. Sweden’s NDC system, Germany’s sustainability factor, and Japan’s macroeconomic slide are examples of mechanisms designed to reduce the need for repeated discretionary reforms. In the Japanese context, Imrohoroglu and Sudo (2011), Braun and Joines (2015), Kitao (2015), Imrohoroglu, Kitao, and Yamada (2016), Hansen and Imrohoroglu (2016), and Hansen and Imrohoroglu (2023) quantify macroeconomic and welfare consequences of alternative pension reforms. The cross-country statistics in this paper are much simpler than these structural analyses, but they speak to the same principle: adjustment adopted early creates fiscal space, because small annual changes

compound over decades.

A closely related applied literature produces cross-country projections of the fiscal cost of population aging.² The OECD’s *Pensions at a Glance* reports document pension rules, recent pension reforms, and cross-country differences in retirement ages, benefit formulas, and old-age support ratios. The European Commission’s *Ageing Report* provides long-run projections of age-related public expenditure on pensions, health care, long-term care, and education for EU countries, while IMF work emphasizes the implications of aging for fiscal sustainability, pension reform, and the composition of public spending. A complementary approach is developed in the National Transfer Accounts literature, which uses age profiles of labor income, consumption, taxes, transfers, and saving to measure how changing population age structure affects intergenerational resource flows and fiscal support ratios. Relative to these institutional and fiscal-projection exercises, the contribution of this paper is to use a common demographic input and a deliberately simple accounting framework to compare the timing of aging, the retirement-boundary equivalent implied by unchanged old-age dependency ratios, and the associated Solow growth drag across a broad set of economies.

A third strand studies the relationship between population age structure and growth. The neoclassical point of departure is [Cutler, Poterba, Sheiner, and Summers \(1990\)](#), who analyze how a rising dependency burden affects saving, capital intensity, and the appropriate policy response in a Solow framework. A large subsequent literature relates growth to the age composition of the population; [Bloom, Canning, Fink, and Finlay \(2007\)](#), for instance, study the growth dividend from a rising working-age share. A recurring theme is nonlinearity—the aging–growth relationship is hump-shaped, turning negative only once an economy is well past its demographic transition [An and Jeon \(2006\)](#). That nonlinearity is the empirical counterpart of the early-aging/late-aging distinction that organizes this paper. A parallel line of work in demography and public finance asks whether low fertility is itself the problem it is often taken to be. [Lee, Mason, and members of the NTA Network \(2014\)](#), using National Transfer Accounts data for forty countries, find that the fertility rate most favorable to government budgets lies well above replacement while the rate most favorable to the material standard of living lies near or below it, once the cost of equipping a growing labour force with capital is counted; see also [Striessnig and Lutz \(2013\)](#). [Lutz \(2007\)](#) frames the resulting policy choice as one between raising fertility and adapting institutions to persistently low fertility. Section [3.7](#) takes up the timing of that choice.

The recent cross-country evidence is mixed in sign, which is part of what motivates a transparent accounting approach. [Acemoglu and Restrepo \(2017\)](#) find no negative cross-country relationship between aging and growth—if anything a positive one—and attribute the offset to faster automation in aging economies. [Maestas, Mullen, and Powell \(2023\)](#), exploiting variation across U.S. states, instead estimate a sizable negative effect: a ten-percentage-point increase in the population share aged 60 and over lowers GDP per capita by about five percent, roughly two-thirds of it through slower productivity growth. [Aksoy, Basso, Smith, and Grasl \(2019\)](#) find that age structure shapes investment and innovation as well as growth. In the same panel-based vein, [Kotschy and Bloom \(2023\)](#) document that the demographic dividend becomes a demographic drag as countries advance through

²See [OECD \(2023\)](#), [European Commission, Directorate-General for Economic and Financial Affairs \(2024\)](#), [International Monetary Fund \(2025\)](#), and [Lee and Mason \(2011\)](#).

the later stages of the transition, estimating the growth effect of changing working-age shares in a standard empirical growth model across roughly seventy countries. The present paper reaches a similar conclusion by a different route: rather than estimating the effect from historical panel variation, I impose a calibrated Solow structure, project it forward under common demographic assumptions for 103 countries, and use a Shapley decomposition to separate the demographic channel from a distinct TFP-path channel—a separation the reduced-form estimates do not provide.

The paper’s methodological point of departure is [Fernández-Villaverde, Ventura, and Yao \(2025\)](#), who argue that conventional GDP per capita can misrepresent performance in fast-aging economies and introduce working-age population as the relevant labor input in the production function. I adopt this insight in the Solow exercise, using working-age population rather than total employment as the labor input, and extend their framework to 103 countries while separating the demographic component from a distinct TFP-path component that they do not isolate. While [Fernández-Villaverde, Ventura, and Yao \(2025\)](#) use PWT employment in their TFP calibration, this paper uses WPP working-age population throughout for internal consistency with the demographic projection; Appendix [D](#) documents the implications.

A fourth strand concerns productivity convergence. [Fernández-Villaverde, Ohanian, and Yao \(2026\)](#) develop the growth-accounting perspective used here to discipline country-specific TFP paths and emphasize the slowdown that follows when fast-growing economies approach the technological frontier. I extend this logic beyond China by computing a TFP-path component for countries with recent TFP growth above the U.S. frontier rate and for countries with negative historical TFP growth. This is an accounting exercise rather than a structural forecast, but it is useful because it separates a demographic headwind from a productivity-convergence headwind.

A closely related paper is [Hayashi \(2026\)](#), who argues that Japan’s rapid population aging is the root cause of its post-1990 reversal of fortune. His mechanism runs through TFP: measuring aging by the old-to-young ratio—the population aged 50–79 relative to that aged 20–49—he documents a negative relationship between the *level* of that ratio and per-worker GDP growth among economies that have completed the demographic transition. Quasi-differencing the canonical growth equation across the 1960–1990 and 1990–2020 periods absorbs the unobserved steady-state level and the convergence (Baumol) term into lagged growth, leaving an “aging speed”—the change in the old-to-young ratio—as the sole regressor for quasi-differenced TFP growth. An OLS regression on 25 early transitioners yields a slope of -3.31 at a two-percent convergence speed, implying that, absent its rapid aging, Japan’s per-worker growth over 1990–2020 would have been about 2.1 percentage points higher. The resulting out-of-sample projection has the United States outgrowing continental Europe, the Asian Tigers, and Japan through 2050; the China–U.S. ratio of aggregate PPP GDP, near 1.15 in 2020, is projected to fall toward and possibly below one by 2050, depending on the assumed speed of convergence. The projection is a reduced-form best-linear-predictor exercise—an overlapping-generations model of technology adoption motivates the functional form but is not structurally estimated.

The present paper is complementary in method and aim. Rather than estimating an aging–TFP relationship, I keep the demographic and TFP-path channels distinct inside a calibrated Solow accounting framework applied to 103 countries. The direct demographic

channel is the effect of changes in the working-age share; the TFP-normalization component captures the effect of bringing country-specific TFP growth rates toward a long-run benchmark. A Shapley decomposition then assigns growth drag between these two channels. The distinction matters because the central object here is not growth alone but the joint comparison of growth drag and fiscal compression. Two implications follow. First, if aging also depresses TFP growth through Hayashi’s channel, the direct demographic effect measured here is a conservative accounting component rather than the full macroeconomic effect of aging. Second, under that same mechanism part of the TFP-normalization component is itself demographic in origin, so the decomposition should be read as an accounting split rather than a causal attribution.

[Fernández-Villaverde, Ventura, and Yao \(2025\)](#) is the closest antecedent to the growth-accounting part of this paper, but the aim here is different. The objective is not to develop a new growth model; it is to use a common demographic input to compare two distinct margins of the aging transition across countries: the fiscal compression implied by rapidly rising old-age dependency ratios, and the demographic growth effect implied by changes in working-age population shares. The Solow exercise is thus a transparent accounting device to be placed alongside the demographically equivalent retirement boundary. Treating the fiscal and growth margins within one framework is what lets the central empirical point emerge: fiscal urgency and growth effects are distinct dimensions of aging that need not coincide across countries—a country can face a large retirement-boundary adjustment without a correspondingly large Solow demographic drag.

The choice of fertility baseline is consequential. [Jones \(2019\)](#) reviews policy responses to ultra-low fertility in East Asia, while [Kearney and Levine \(2022\)](#) documents broad-based fertility decline in the United States. [Fernández-Villaverde \(2025\)](#) argues that recent vital-registry data have often come in below WPP medium projections. These findings motivate using the WPP low-fertility variant as the baseline and treating the medium variant as an optimistic sensitivity, since for the economies with the most severe projected aging — Korea, China, and Japan — the medium variant embeds a fertility rebound that has not yet materialized.

The paper’s contribution is to bring these strands together in a single, deliberately transparent framework applied to a common set of 103 economies. It documents how quickly countries cross key old-age dependency thresholds, translates the projected age structure into a demographically equivalent retirement boundary, and then uses a calibrated Solow model with a Shapley decomposition to separate the demographic growth effect from a distinct TFP-normalization scenario. The result is a unified set of benchmarks for the speed, fiscal scale, and growth consequences of demographic aging.

3 Demographic Aging and Fiscal Adjustment

Throughout this section, I measure population aging using the old-age dependency ratio. Let $N_{a,t}^i$ denote the population of country i at age a in year t . The baseline old-age dependency ratio is defined as

$$\text{OADR}_{65,t}^i \equiv \frac{\sum_{a=65}^{\omega} N_{a,t}^i}{\sum_{a=20}^{64} N_{a,t}^i},$$

where ω denotes the maximum age reported in the population data. Thus, $\text{OADR}_{65,t}^i = 0.50$ means that there is one person aged 65 or older for every two working-age persons aged 20–64. When useful, I also report an alternative measure based on a retirement boundary of age 70,

$$\text{OADR}_{70,t}^i \equiv \frac{\sum_{a=70}^{\omega} N_{a,t}^i}{\sum_{a=20}^{69} N_{a,t}^i}.$$

To ground the cross-country comparisons that follow, I begin with Japan—the country that has experienced population aging most intensively among all economies and has reached the highest current dependency ratio. Several European economies crossed earlier OADR thresholds before Japan, but Japan moved fastest through high dependency levels and remains the benchmark for extreme aging. Then I examine the extent of aging in the U.S. economy using population projections from four different sources. Next, I document aging in a few selected early and late aging economies. Finally, I use the WPP data to characterize projected aging in the full 103-country sample.

3.1 Aging in Japan

Figure 1 illustrates why Japan is the natural benchmark for the rest of the paper. The six projection waves from the Institute of Social Security and Population (IPSS) do not merely show a high level of old-age dependency; they show mostly repeated downward revisions in the underlying demographic outlook until the 2017 wave. Each new projection before then shifted the expected dependency path upward, implying that a pension system calibrated to earlier demographic assumptions would become increasingly underfunded even without any change in benefit rules.

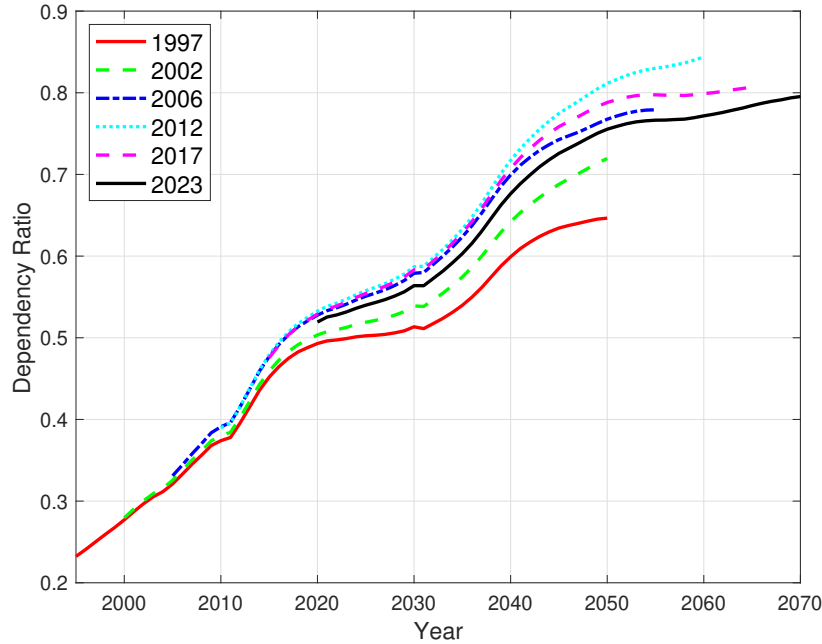


Figure 1: Dependency Ratios Implied by Six IPSS Projection Waves

Notes: Each line represents a successive IPSS projection wave (1997–2023). The 2002 wave prompted Japan’s 2004 pension reform. 2024 births fell below the most pessimistic 2023 forecast.

The timing is also informative. The 2002 projection wave arrived before the dependency ratio had reached its subsequent extreme levels, and it helped motivate the 2004 macroeconomic slide. Japan therefore provides both a warning and a policy precedent: when fertility and longevity surprises arrive persistently in the same direction, early automatic adjustment can spread the fiscal burden across cohorts before the old-age dependency ratio becomes very high.³

3.2 Aging in the United States

Four institutions publish U.S. population projections: the Congressional Budget Office (CBO), Social Security Administration (SSA), the Census Bureau (CB), and UN WPP. Figure 2 compares their medium-variant OADRs alongside CB immigration scenarios. The OADR from the CB, CBO, and WPP converge to roughly 55% by 2100 from 32% in 2024; SSA is more optimistic at 45%. Immigration uncertainty is substantial: CB’s high- versus zero-immigration scenarios differ by 25 percentage points by 2100.⁴

³Japan’s *macroeconomic slide* (*makuro keizai suraido*) was introduced in the 2004 pension reform as an automatic adjustment mechanism: it reduces the annual indexation of benefits by a factor reflecting the decline in the number of contributors and rising life expectancy, gradually lowering the replacement rate until the system is projected to be sustainable. Because it operates only when benefits would otherwise rise, deflation kept it dormant until its first application in fiscal year 2015. It is the leading real-world example of the automatic-adjustment principle emphasized here: small annual changes, applied early, compound into large fiscal savings over the horizon.

⁴Panel (a) plots medium-variant OADRs from the Census Bureau, CBO, and UN World Population Prospects 2024 against the SSA intermediate (best-estimate) projection. The four series are nearly indistinguishable through about 2055 and diverge only thereafter, with the SSA path flattening near 0.45 by 2100 while the others continue rising to 0.54–0.56. The divergence reflects differences in assumed fertility: the [Social Security Administration, Office of the Chief Actuary \(2024\)](#) intermediate assumptions have the U.S. total fertility rate recovering to an ultimate 1.9 children per woman, whereas [Congressional Budget Office \(2025\)](#) converges to about 1.58, the Census Bureau to about 1.52, and the WPP 2024 medium variant to about 1.65 by 2100; because additional births enter the working-age denominator only with a roughly twenty-year lag, the higher SSA fertility assumption lowers its dependency ratio only in the second half of the horizon. The series also rest on slightly different population universes—the Census Bureau and the UN use the resident population of the 50 states and the District of Columbia, while CBO and SSA use the broader Social Security area population that adds the territories and citizens abroad—but because this shifts the numerator and denominator in partly offsetting ways, it affects the dependency *ratio* only modestly and does not account for the late-horizon gap. Differences in immigration and mortality assumptions are likewise minor.

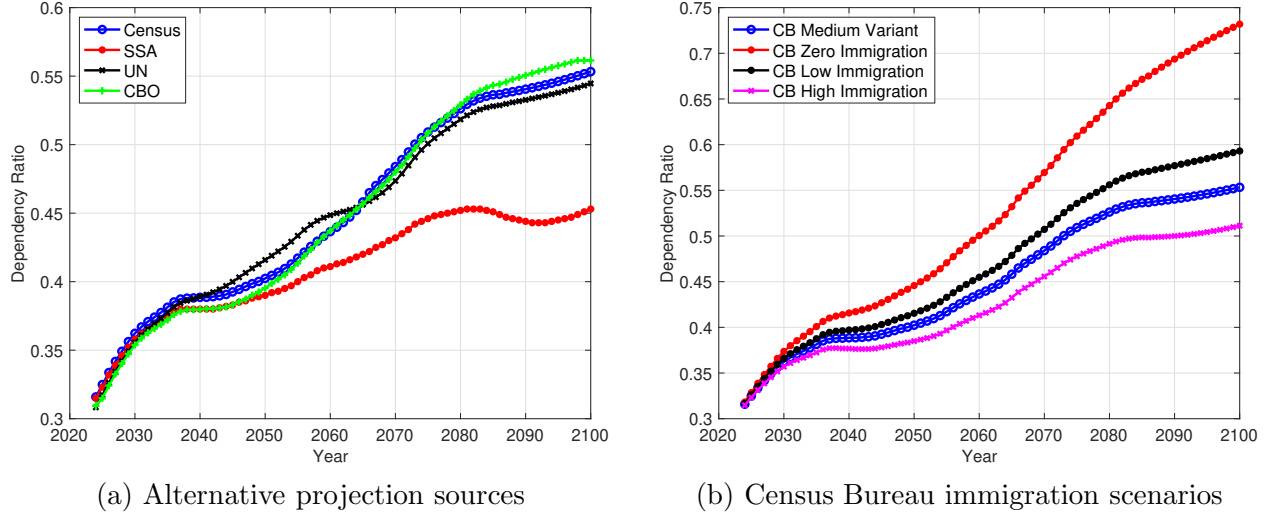


Figure 2: U.S. Old-Age Dependency Ratio Projections

Notes: Panel (a): medium-variant OADRs from CB, CBO, UN, and SSA. Panel (b): CB projections under four immigration assumptions; the high-zero gap reaches 25 pp by 2100.

The U.S. comparison is useful for two reasons. First, the United States is old enough to face meaningful pension pressure but remains younger than Japan and most of Western Europe. The main projection sources therefore agree on the direction of aging but differ in the terminal level of the OADR, with SSA’s assumptions producing a less severe path than the CB, CBO, and UN series. Second, the Census Bureau immigration scenarios show that migration can materially affect the dependency ratio, but it does not eliminate aging. Even under more favorable immigration assumptions, the U.S. OADR rises substantially over the century. The United States is therefore an intermediate case: demographic pressure is milder than in Japan, Korea, or China, but the fiscal consequences remain large because the initial pension system is large and the adjustment horizon is finite.

3.3 Select Early- and Late-Aging Economies

Figure 3 plots OADRs for a few additional economies. Panel (a) shows the OADRs from Japan, the United States, and six European economies—Denmark, France, Germany, Italy, Spain, and the United Kingdom. These countries are already old in 2024, and their projected paths are comparatively smooth. Japan remains the most aged economy in the panel, while the United States remains the youngest. The European economies converge toward a relatively narrow range by 2100, reflecting the fact that much of their demographic transition has already taken place.

Panel (b) contrasts this early-aging pattern with five late-aging economies: Brazil, China, India, Korea, and Türkiye, along with Japan as the benchmark early-aging economy. The ordering of the late-aging economies in the discussion is alphabetical to emphasize that the point is not a country ranking in 2024 but the shape of the trajectories. China and Korea begin the projection period with much lower OADRs than Japan, but their paths steepen rapidly and overtake Japan around mid-century. Brazil, India, and Türkiye do not reach the same extreme levels as China and Korea under the medium variant, but their increases

are large relative to their 2024 starting points. The figure therefore previews the central distinction of the paper: early-aging economies are already old, while late-aging economies face a larger remaining transition compressed into fewer decades. Note that Figure 3 uses the medium variant to show that the late-aging pattern is already visible under the more optimistic projection; the main tables use low fertility.

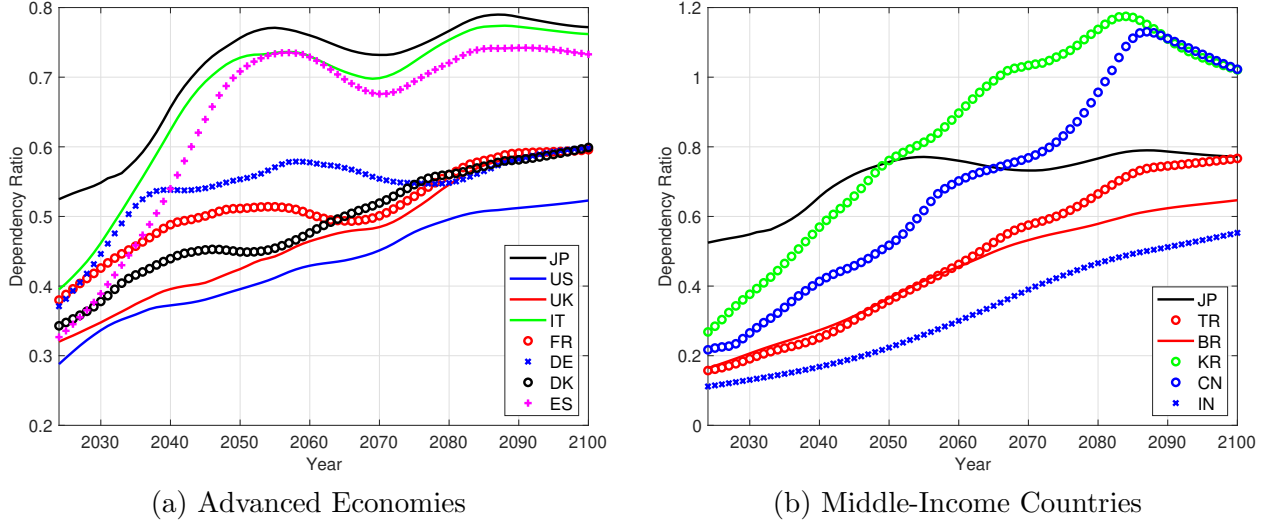


Figure 3: Old-Age Dependency Ratios: Early- vs. Late-Aging Economies

Notes: UN WPP 2024 medium fertility. Panel (a): Japan, United States, Denmark, France, Germany, Italy, Spain, and United Kingdom. Panel (b): Brazil, China, India, Japan, Korea, and Türkiye. Korea and China overtake Japan around mid-century; both exceed an OADR of 100% later in the century.

For China and Korea, the WPP medium variant already projects OADRs close to or above 100% by 2100. Under the low-fertility variant, the projected OADR reaches 121.3% for Japan and approximately 200% for Korea and China.

Fertility scenarios and baseline choice. The choice between fertility scenarios carries substantial implications for projected old-age dependency ratios and required pension adjustments. For the main results of this paper, I use the UN WPP low-fertility variant as the main baseline and treat the medium variant as an optimistic robustness case. This choice reflects the fact that the WPP medium variant embeds a sustained fertility rebound that has not materialized in many ultra-low-fertility economies. Recent outcomes in China, Korea, Japan, Singapore, Chile, and Thailand are closer to the WPP low variant—and in some cases below it—than to the rebound path embedded in the medium variant. Independent projections from the Institute for Health Metrics and Evaluation (IHME) point in the same direction for several selected countries⁵. The main tables below therefore emphasize

⁵IHME's Global Burden of Disease fertility projections use a methodology independent of the UN WPP projections. In Appendix B, I compare the WPP medium and low variants with IHME reference and lower-bound projections. For selected countries such as the United States, Japan, China, Korea, Spain, Brazil, Türkiye, and India, the IHME reference path is generally closer to WPP low than to the stronger fertility rebound embedded in WPP medium, although the exact ranking differs by country and horizon. The sources are the UN WPP 2024 revision

low fertility, while medium-fertility counterparts and the fuller WPP–IHME comparison are collected in the appendices.

3.4 Old-Age Dependency Ratios in the Larger Sample

Table 1 presents old-age dependency ratios for 34 early-aging countries spanning current conditions in 2024 and projections through 2100 under alternative fertility assumptions. Table 2 shows the corresponding results for 69 late-aging countries. The cross-country variation in both levels and trajectories reveals the fundamental distinction between early-aging and late-aging economies that motivates this study. The 30% OADR threshold produces the 34/69 grouping used throughout; results are robust to alternative cutoffs of 28% and 32%.⁶ A 28% cutoff moves three borderline economies from late- to early-aging (South Korea, Belarus, and Russia), while a 32% cutoff moves up to six economies from early- to late-aging (Norway, United States, Ukraine, Slovakia, Australia, and New Zealand). In neither case does this alter any main finding, since all borderline economies exhibit the same qualitative pattern as the larger group to which they are assigned. The early/late grouping is therefore a level-based taxonomy rather than a direct measure of transition speed. For this reason, the paper separately reports threshold-crossing speeds in Section 3.6 and uses those speeds directly in the fiscal-growth correlation analysis of Section 4.7.

United Nations, Department of Economic and Social Affairs, Population Division (2024) and the Global Burden of Disease fertility forecasting study GBD 2021 Fertility and Forecasting Collaborators (2024).

⁶A different tradition in demography classifies countries by whether they have *completed* the demographic transition rather than by the level they have reached. Chesnais (1992) treats a country as post-transitional when life expectancy at birth exceeds 50 years, fertility or the crude birth rate has declined persistently, and the crude birth rate has fallen below 30 per thousand; Cervellati and Sunde (2011) implement a version of these criteria. The two taxonomies answer different questions. Theirs identifies the point at which modern growth regimes are expected to apply, which is why it is the right partition for growth regressions. Mine identifies where an economy currently sits on the old-age dependency path, which is what determines the scale of the pension adjustment ahead of it. The distinction matters here because most of the economies in this sample completed the demographic transition long ago and yet differ enormously in how much of the *aging* transition remains in front of them. The two partitions are closely related in practice, and the differences are interpretable. All 34 economies classified as early-aging here are among the 52 post-transitioners as of 1990 in Hayashi (2026): twenty-one are in his 25 “early transitioners” (post-transitional as of 1960), and the remaining thirteen—twelve of them Eastern European, plus Hong Kong—are in his 1990 set, absent from the 1960 set largely because 1960 GDP data are unavailable for the former Soviet bloc rather than on demographic grounds (his footnote 10). Four of his 25 are not classified as early-aging here: Ireland, Iceland, and Uruguay, which completed the demographic transition early but retain 2024 old-age dependency ratios below 30 percent, and Luxembourg, which falls below the population threshold used to construct this sample. The three substantive exceptions are exactly the intended distinction: what matters for the pension adjustment ahead is where an economy currently sits on the dependency path, not when its fertility decline began.

Table 1: Old-Age Dependency Ratios: Early-Aging Economies

Country	OADR (%)			Country	OADR (%)		
	2024	Med	Low		2024	Med	Low
Japan	54.9	79.9	121.3	Belgium	35.7	64.9	90.8
Finland	42.8	68.5	97.5	Hungary	35.4	57.7	81.2
Portugal	42.5	62.0	85.4	Spain	34.9	75.9	113.2
Italy	42.0	79.1	120.1	Netherlands	34.8	64.8	91.0
Greece	41.6	74.1	111.1	Austria	34.1	67.7	95.5
Croatia	40.3	74.5	117.9	Romania	34.1	65.9	106.3
France	40.2	61.8	85.9	United Kingdom	34.0	62.1	86.3
Germany	39.8	62.0	85.8	Poland	33.7	83.8	141.4
Serbia	39.1	72.1	116.4	Lithuania	33.5	84.2	154.2
Latvia	37.9	74.4	125.0	Switzerland	33.3	64.5	87.3
Bulgaria	37.7	64.8	103.1	Canada	33.2	58.8	75.5
Slovenia	37.3	65.0	92.7	Norway	31.9	66.9	94.5
Estonia	37.1	72.9	113.5	USA	30.8	54.5	72.2
Sweden	36.8	64.3	88.2	Ukraine	30.7	90.2	176.7
Denmark	36.3	62.4	86.9	Slovakia	30.6	71.5	111.2
Hong Kong	36.0	193.1	537.1	Australia	30.2	55.5	71.1
Czechia	35.7	60.9	87.3	New Zealand	30.2	55.5	71.1
<i>Mean</i>	36.4	71.7	114.6				

Notes: OADR = population aged 65+ / population aged 20–64 (%). The full sample of 103 countries is sorted by 2024 OADR (descending), with 34 early-aging economies (OADR $\geq$ 30% in 2024) and 69 late-aging economies (OADR $<$ 30%). Med and Low = UN WPP 2024 medium and low fertility projections for 2100.

Among early-aging economies, Japan exhibits the highest current dependency ratio at 54.9%, reflecting its position as the world’s most aged society. Other advanced economies display substantial but lower ratios, with Finland, Portugal, Italy, Croatia, France, and Greece all above 40% in 2024. The median early-aging economy has a 2024 dependency ratio of roughly 35%, indicating that there is already about one person aged 65 and above for every three working-age adults. Under the low-fertility variant, the mean OADR for this group rises from 36.4% in 2024 to 114.6% in 2100. Several early-aging countries therefore move from already-high dependency ratios to levels at or above one elderly person per working-age adult. Japan reaches 121.3%, Italy 120.1%, Bulgaria 103.1%, Poland 141.4%, Ukraine 176.7%, and several other Eastern European economies exceed 120%.⁷ These numbers underscore that early-aging countries are not finished aging; rather, they start from a high base and continue to deteriorate under persistent low fertility.

⁷Hong Kong is a further outlier at 537.1%. As a small, highly urbanized special administrative region of China with one of the world’s lowest fertility rates, its long-horizon WPP projections are correspondingly more sensitive to migration and boundary assumptions than those of larger economies, so this figure is best read as indicative of severe aging pressure rather than a precise level.

Table 2: Old-Age Dependency Ratios: Late-Aging Economies

Country	OADR (%)			Country	OADR (%)		
	2024	Med	Low		2024	Med	Low
South Korea	29.3	105.9	196.2	Bangladesh	11.7	65.0	103.2
Belarus	29.1	72.6	124.6	Paraguay	11.6	47.9	70.4
Russia	28.6	49.5	68.4	South Africa	11.3	32.8	44.0
Uruguay	27.3	79.0	132.2	Cambodia	11.3	43.2	63.4
Ireland	27.1	67.6	99.7	Uzbekistan	10.6	34.7	46.1
Iceland	26.1	74.4	110.4	Bolivia	10.2	37.8	53.2
Israel	24.1	45.4	58.6	Philippines	9.7	47.9	72.9
Thailand	24.0	72.5	111.7	Egypt	9.5	39.8	54.6
China	23.1	106.4	206.8	Mongolia	9.4	43.4	60.5
Chile	22.5	94.8	161.3	Guatemala	9.1	48.4	71.9
Argentina	21.3	69.7	109.7	Pakistan	8.8	28.8	38.4
Sri Lanka	20.9	66.3	103.5	Rwanda	8.3	31.9	41.9
Singapore	19.8	88.9	135.9	Jordan	8.2	47.8	64.9
Costa Rica	19.8	89.5	148.8	Zimbabwe	8.2	26.5	35.9
Brazil	17.7	67.7	106.5	Honduras	8.0	46.9	67.3
Türkiye	16.8	80.3	133.5	Senegal	7.7	31.6	41.4
Panama	16.2	62.6	90.9	Ghana	7.4	29.4	39.1
Tunisia	16.1	68.2	108.1	Tanzania	7.0	23.3	29.3
Kazakhstan	16.0	41.0	55.3	Ethiopia	6.9	30.6	39.7
Peru	15.8	64.2	96.4	Iraq	6.9	34.3	46.0
Colombia	15.7	73.7	117.4	Nigeria	6.8	20.3	25.9
Viet Nam	15.0	62.0	95.9	Angola	6.8	19.9	25.0
Ecuador	14.3	66.5	102.6	Sudan	6.6	21.2	27.6
Morocco	14.1	59.5	92.7	Niger	6.6	21.8	27.4
Mexico	14.0	63.5	100.9	Mozambique	6.6	21.3	27.9
El Salvador	14.0	65.8	112.8	Mali	6.5	18.4	22.8
Dominican Rep.	13.8	53.2	81.0	Cameroon	6.2	24.0	30.8
Azerbaijan	13.7	52.7	75.7	Kenya	6.1	28.0	38.2
Iran	13.2	72.9	114.9	Burkina Faso	6.0	24.1	31.7
Malaysia	12.4	58.4	82.1	Malawi	5.8	28.7	38.5
Indonesia	12.2	47.8	69.4	Côte d'Ivoire	5.7	17.5	21.6
Myanmar	12.1	42.4	63.4	Uganda	5.1	36.1	50.3
India	12.0	58.1	87.4	Saudi Arabia	4.5	27.6	32.7
Algeria	11.9	56.1	80.2	Zambia	4.3	24.9	32.6
Nepal	11.8	55.0	88.6				
Mean	13.1	50.1	76.0				

Notes: OADR = population aged 65+ / population aged 20–64 (%).
N = 69 late-aging (OADR < 30%). Sorted by 2024 OADR (descending).
Medium (Med) and Low fertility from UN World Population Prospects
2024 Revision.

Late-aging economies occupy a markedly different position in 2024. Korea is still below the early-aging cutoff at 29.3%, China is at 23.1%, Brazil at 17.7%, Türkiye at 16.8%, and India at only 12.0%. The table therefore contains many countries that appear young today but age dramatically over the rest of the century. Even under the medium-fertility variant, China and Korea reach OADRs above 100% by 2100, implying more than one elderly person for each working-age adult. Several late-aging economies approach levels that would today be considered extreme under medium fertility: Chile 94.8%, Singapore 88.9%, Costa Rica 89.5%, Türkiye 80.3%, and Thailand 72.5%.

The low-fertility variant produces much more severe outcomes. Korea reaches 196.2% and China 206.8%, roughly two elderly persons per working-age adult. Chile, Thailand, Singapore, Sri Lanka, Brazil, Argentina, Costa Rica, Colombia, Ecuador, Iran, and Türkiye all reach or exceed an OADR of 100% under low fertility. Thus, the low-fertility scenario is not merely a uniform upward shift in projected aging; it changes the qualitative nature of

the problem for many late-aging economies by moving them into dependency ratios with no historical precedent among large economies.

The United States occupies an intermediate position. Its OADR rises from 30.8% in 2024 to 54.5% under medium fertility and 72.2% under low fertility. This path is less severe than those of Japan, Korea, or China, partly because of higher fertility and sustained immigration, at least until recently, but it is still large enough to create meaningful pressure on Social Security and the federal budget. Australia, Canada, United Kingdom, and New Zealand show broadly similar patterns: aging is substantial, but less compressed than in the fastest late-aging economies.

3.5 Heterogeneity in Aging Speed Across Countries

The demographic transition toward aged societies exhibits substantial heterogeneity both in timing and pace across developed and developing economies. To systematically characterize these patterns, we examine the time required for countries to traverse key thresholds of the old-age dependency ratio (OADR), defined as the population aged 65 and above relative to the working-age population (20–64).

Measuring aging speed. Using the notation introduced at the beginning of Section 3, let T_τ^i denote the first year in which country i 's old-age dependency ratio reaches threshold τ :

$$T_\tau^i \equiv \min \{t : \text{OADR}_{65,t}^i \geq \tau\}.$$

I focus on four thresholds, $\tau \in \{0.125, 0.25, 0.50, 1.00\}$, corresponding respectively to eight, four, two, and one working-age persons per person aged 65 and above. The speed of aging between successive thresholds is defined as

$$S_{0.25}^i \equiv T_{0.25}^i - T_{0.125}^i, \quad S_{0.50}^i \equiv T_{0.50}^i - T_{0.25}^i, \quad S_{1.00}^i \equiv T_{1.00}^i - T_{0.50}^i.$$

Thus, $S_{0.25}^i$ is the number of years it takes country i to move from an OADR of 0.125 to 0.25, $S_{0.50}^i$ is the number of years required to move from 0.25 to 0.50, and $S_{1.00}^i$ is the number of years required to move from 0.50 to 1.00. Smaller values of S_τ^i therefore indicate faster demographic compression. Crossing years are computed using UN WPP historical estimates for 1950–2023 and WPP 2024 low-fertility projections for 2024–2100.

Table 3 summarizes these transitions for selected benchmark countries under the low-fertility variant. The table reports the year each country crosses the OADR thresholds 0.125, 0.25, 0.50, and 1.00, together with the number of years required to move between adjacent thresholds. It therefore combines information about levels—how old each economy is in 2024 and how old it is projected to become by 2100—with information about speed—how quickly the transition takes place. The countries are sorted by their 2024 OADR so that the earliest-aging economies appear first.

Table 3: Selected Aging-Speed Benchmarks Under Low Fertility

Country	OADR 2024	2100 Low	Year $T_{0.125}$	$S_{0.25}$	Year $T_{0.25}$	$S_{0.50}$	Year $T_{0.50}$	$S_{1.00}$	Year $T_{1.00}$
Japan	54.9	121.3	1974	23	1997	19	2016	61	2077
Finland	42.8	97.4	1954	47	2001	44	2046	—	—
Portugal	42.5	85.3	1950	44	1994	37	2032	—	—
Italy	42.0	120.0	1950	41	1991	39	2030	48	2078
Greece	41.6	111.0	1950	43	1993	41	2034	49	2083
France	40.2	85.9	1950	27	1977	61	2038	—	—
Germany	39.8	85.8	1950	22	1972	60	2031	—	—
Sweden	36.8	88.2	1950	23	1973	80	2053	—	—
Spain	34.9	113.2	1950	45	1995	41	2036	45	2081
United States	30.8	72.2	1950	67	2017	47	2064	—	—
Ukraine	30.7	176.6	1950	67	2017	32	2049	25	2074
Korea	29.3	196.1	2003	18	2021	14	2035	23	2058
China	23.1	206.8	2004	24	2027	18	2046	25	2071
Chile	22.5	161.2	1994	34	2027	24	2052	21	2072
Brazil	17.7	106.5	2014	20	2034	24	2058	32	2090
Türkiye	16.8	133.5	2013	25	2037	20	2058	24	2082
India	12.0	87.4	2025	25	2051	21	2071	—	—

Notes: OADR is population aged 65+ divided by population aged 20–64. T_x is the first year in which the old-age dependency ratio reaches threshold x . $S_{0.25} = T_{0.25} - T_{0.125}$, $S_{0.50} = T_{0.50} - T_{0.25}$, and $S_{1.00} = T_{1.00} - T_{0.50}$. Smaller values of S_x indicate faster demographic compression. Crossing years are computed by linear interpolation between annual observations using UN WPP historical estimates for 1950–2023 and WPP 2024 low-fertility projections for 2024–2100; T_x and S_x are rounded to the nearest year for presentation. The 2100 column reports the projected OADR level under the WPP low-fertility variant. Countries are sorted by 2024 OADR. A ‘—’ symbol means that the 1.0 threshold for the OADR is not reached by 2100.

The table highlights the contrast between countries that aged early and those whose most consequential demographic adjustment still lies ahead. The data allow precise cross-country comparisons along three speed dimensions.

$S_{0.25}$ (12.5% to 25% OADR). Japan took 23 years to move from OADR = 12.5% (1974) to OADR = 25% (1997). Germany accomplished the same doubling in 22 years (1950–1972) and Sweden in 23 years (1950–1973)—strikingly similar paces, confirming that the early industrializers of Europe and Japan traversed the initial threshold band at comparable speeds, despite very different institutional contexts. France moved slightly slower at 27 years (1950–1977). Southern European latecomers were considerably slower: Spain 45 years, Portugal 44 years, and Italy 41 years, reflecting that they crossed the 12.5% threshold later and from a lower base. Korea, by contrast, accomplished the same interval in only 18 years (2003–2021)—meaningfully faster than Japan. China is projected to complete it in 24 years (2004–2027), essentially the same speed as Japan but compressed into the recent past.

$S_{0.50}$ (25% to 50% OADR). Japan took 19 years for this doubling (1997–2016). Korea is projected to traverse it in only 14 years (2021–2035)—one-quarter faster than Japan—driven by the uniquely steep fertility cliff. China is projected at 18 years (2027–2046), close

to Japan on this metric. The contrast with gradual-aging Europe is stark: Germany requires 60 years (1972–2031) and Sweden 80 years (1973–2053) for the same band, allowing multiple generations of institutional adaptation that Korea and China simply will not have.

$S_{1.00}$ (**50% to 100% OADR**). Reaching $OADR = 1.00$ means one elderly person for every working-age adult—a level without historical precedent among large economies. Under low fertility, it becomes part of the baseline path for Japan, Korea, China, and others. Japan is projected to cross this threshold around 2077, 61 years after reaching 0.50 in 2016. Korea faces the same crossing in only 23 years (2035–2058) and China in 25 years (2046–2071)—less than half of Japan’s window. Ukraine also faces a rapid $S_{1.00} = 25$ years (2049–2074), driven by its post-Soviet fertility collapse. The implication is direct: Korea and China face not only larger total increases in dependency ratios but a substantially shorter institutional window in which to reform pension systems, health-care financing, and labor markets compared with Japan or Western Europe.

3.6 The Demographically Equivalent Retirement Boundary

Throughout, FRA denotes the full retirement age—the age at which an individual becomes eligible for unreduced public pension benefits. So far, policy responses to rising OADRs and the fiscal burden on public pension plans have been quite different across economies. In some cases, early eligibility has been postponed, the number of years worked to earn full retirement benefits has been changed, the FRA has been phased up, replacement rates reduced, payroll tax rates have been raised, penalties for early claiming have increased, etc. Given the large number of responses in different countries, it is useful to have one simple metric that can be relatively easily applied to all countries to measure the timing and extent of aging and the pressures on public pension programs.

The retirement-boundary statistic also has a simple fiscal interpretation in a stylized pay-as-you-go pension system. Let R_t denote the retired population, L_t the working-age population, w_t the wage, b_t the replacement rate measured as a fraction of the wage, and τ_t the payroll tax rate required for period-by-period balance. The PAYG budget constraint is

$$\tau_t w_t L_t = b_t w_t R_t,$$

so that

$$\tau_t = b_t \frac{R_t}{L_t} = b_t OADR_t.$$

Thus, conditional on an unchanged replacement rate and payroll-tax base, holding the old-age dependency ratio at its 2024 level is equivalent to holding the required payroll tax rate at its 2024 level. The demographically equivalent retirement boundary therefore summarizes the age-structure adjustment needed to keep the PAYG tax burden unchanged absent benefit cuts, contribution-base expansions, immigration, higher participation, or other financing changes.

Following [De Nardi, Imrohoroglu, and Sargent \(1999\)](#), I translate the projected age structure into a common retirement-boundary equivalent. Using age 65 as the initial boundary and ages 20–64 as the initial working-age population, I calculate the boundary X in 2100

that reproduces each country’s 2024 OADR. Specifically, I solve:

$$\frac{\sum_{a=X}^{\omega} N_{a,2100}^i}{\sum_{a=20}^{X-1} N_{a,2100}^i} = \frac{\sum_{a=65}^{\omega} N_{a,2024}^i}{\sum_{a=20}^{64} N_{a,2024}^i}, \quad (1)$$

for X , where ω is the oldest age reported in the WPP data.

I report two transformations of X : $\Delta\text{FRA} = X - 65$, the change from a common age-65 boundary, and $\Delta\text{FRA}_{\text{stat}} = X - \text{FRA}_{\text{stat}}$, the gap relative to the country’s current statutory FRA. The first provides cross-country comparability; the second shows how far current institutions lie from the demographic equivalent. Neither is a recommended or behaviorally feasible retirement age. The calculation mechanically counts everyone below X as working age and everyone above it as old age; it does not incorporate age-specific employment, health, hours, or productivity. At high values, X should therefore be interpreted as evidence that retirement-age policy alone cannot offset the projected age structure.

Tables 4 and 5 present, for each country, the 2024 old-age dependency ratio together with both required-increase measures—from the uniform age-65 baseline (ΔFRA) and from the country’s current statutory retirement age ($\Delta\text{FRA}_{\text{stat}}$)—under the low-fertility baseline. Medium-fertility counterparts are reported in the online appendix, and required increases measured from an age-70 retirement boundary are reported in the online appendix. The statutory retirement ages themselves are listed in the online appendix. The dual presentation of required adjustments reveals how differences in current statutory retirement ages amplify or moderate the policy challenge facing different countries.

Under low fertility, the equivalent boundary rises by 14 years for Japan, 13 years for the United States, 21 years for Brazil and India, 24 years for China and South Korea, and 25 years for Singapore. Values of this magnitude are not plausible single-instrument reforms. They suggest that the large projected adjustment must clearly be shared across retirement ages, benefits, contributions, tax finance, participation, immigration, and other margins.

Table 4: Required Full Retirement Age Postponements: Early-Aging Economies

Country	OADR 2024	FRA Increase (years)		Country	OADR 2024	FRA Increase (years)	
		From age 65	From stat. FRA			From age 65	From stat. FRA
Japan	54.9	14	14	Belgium	35.7	15	15
Finland	42.8	14	14	Hungary	35.4	13	13
Portugal	42.5	12	11	Spain	34.9	18	18
Italy	42.0	17	15	Netherlands	34.8	14	12
Greece	41.6	16	14	Austria	34.1	16	16
Croatia	40.3	15	15	Romania	34.1	15	15
France	40.2	13	14	United Kingdom	34.0	15	14
Germany	39.8	13	11	Poland	33.7	19	19
Serbia	39.1	15	15	Lithuania	33.5	19	19
Latvia	37.9	17	17	Switzerland	33.3	15	15
Bulgaria	37.7	14	14	Canada	33.2	13	13
Slovenia	37.3	15	15	Norway	31.9	16	14
Estonia	37.1	17	17	USA	30.8	13	11
Sweden	36.8	14	14	Ukraine	30.7	21	21
Denmark	36.3	14	12	Slovakia	30.6	17	17
Hong Kong	36.0	26	26	Australia	30.2	14	12
Czechia	35.7	14	14	New Zealand	30.2	14	14

Notes: Required increases in the full retirement age to maintain each country's 2024 OADR through 2100 under the UN WPP 2024 **low**-fertility variant, solving equation (II) for X . "From age 65" = $\Delta\text{FRA} = X - 65$; "From stat. FRA" = $\Delta\text{FRA}_{\text{stat}} = X - \text{FRA}_{\text{stat}}$, where statutory retirement ages are from OECD *Pensions at a Glance* 2024 and national legislation (listed in the online appendix). OADR = $\text{pop}(65+)/\text{pop}(20-64)$ (%). Medium-fertility and age-70-boundary counterparts are reported in the online appendix. $N = 34$; sorted by 2024 OADR (descending).

Table 5: Required Full Retirement Age Postponements: Late-Aging Economies

Country	OADR 2024	FRA Increase (years)		Country	OADR 2024	FRA Increase (years)	
		From age 65	From stat. FRA			From age 65	From stat. FRA
South Korea	29.3	24	24	Bangladesh	11.7	23	28
Belarus	29.1	19	19	Paraguay	11.6	19	19
Russia	28.6	14	14	South Africa	11.3	16	16
Uruguay	27.3	20	20	Cambodia	11.3	18	23
Ireland	27.1	19	18	Uzbekistan	10.6	15	20
Iceland	26.1	19	17	Bolivia	10.2	17	24
Israel	24.1	14	12	Philippines	9.7	20	25
Thailand	24.0	20	25	Egypt	9.5	18	23
China	23.1	24	29	Mongolia	9.4	21	26
Chile	22.5	24	24	Guatemala	9.1	20	20
Argentina	21.3	21	21	Pakistan	8.8	14	19
Sri Lanka	20.9	20	25	Rwanda	8.3	17	22
Singapore	19.8	25	27	Jordan	8.2	23	28
Costa Rica	19.8	24	24	Zimbabwe	8.2	15	20
Brazil	17.7	21	21	Honduras	8.0	21	21
Türkiye	16.8	22	22	Senegal	7.7	16	16
Panama	16.2	21	21	Ghana	7.4	16	21
Tunisia	16.1	22	22	Tanzania	7.0	15	20
Kazakhstan	16.0	15	17	Ethiopia	6.9	17	17
Peru	15.8	21	21	Iraq	6.9	19	24
Colombia	15.7	22	25	Nigeria	6.8	12	17
Viet Nam	15.0	21	26	Angola	6.8	12	17
Ecuador	14.3	22	22	Sudan	6.6	12	17
Morocco	14.1	20	20	Niger	6.6	12	12
Mexico	14.0	22	22	Mozambique	6.6	13	18
El Salvador	14.0	22	27	Mali	6.5	11	11
Dominican Rep.	13.8	19	19	Cameroon	6.2	15	20
Azerbaijan	13.7	20	20	Kenya	6.1	17	22
Iran	13.2	23	23	Burkina Faso	6.0	14	14
Malaysia	12.4	23	28	Malawi	5.8	18	18
Indonesia	12.2	19	26	Côte d'Ivoire	5.7	13	13
Myanmar	12.1	16	21	Uganda	5.1	21	21
India	12.0	21	26	Saudi Arabia	4.5	24	24
Algeria	11.9	21	26	Zambia	4.3	18	23
Nepal	11.8	20	25				

Notes: Required increases in the full retirement age to maintain each country's 2024 OADR through 2100 under the UN WPP 2024 **low**-fertility variant, solving equation (II) for X . "From age 65" = $\Delta FRA = X - 65$; "From stat. FRA" = $\Delta FRA_{stat} = X - FRA_{stat}$, where statutory retirement ages are from OECD *Pensions at a Glance* 2024 and national legislation (listed in the online appendix). OADR = $\text{pop}(65+)/\text{pop}(20-64)$ (%). Medium-fertility and age-70-boundary counterparts are reported in the online appendix. $N = 69$; sorted by 2024 OADR (descending).

The cross-country correlation between 2024 OADR and required FRA increase is $\rho = -0.24$ from age 65 under low fertility, strengthening to -0.51 from statutory baselines. The pooled correlations mask very different within-group patterns, visible in the separate OLS fits of Figure 4: among late-aging economies the correlation is *positive* ($+0.40$ from age 65)—countries further into the OADR ascent require larger adjustments—whereas among early-aging economies it is mildly negative (-0.20), because the highest-OADR early-agers, led by Japan, have already absorbed much of their demographic transition. The pooled correlation is negative only because the early-aging group combines high 2024 OADRs with smaller remaining adjustments. The stronger statutory correlation reflects the amplifying role of low statutory retirement ages: countries with statutory ages below 65 (such as China at 60) face larger required adjustments under this measure, adding dispersion that sharpens the negative relationship with OADR. The correlation between compression speed (OADR

25–50%) and required FRA increase is $\rho = -0.69$, confirming that faster aging translates directly into larger required adjustments. Moving from medium to low fertility raises Korea’s requirement from 21 to 24 years and Japan’s from 7 to 14, illustrating the fertility sensitivity of Section 3.3. The statutory-baseline measure $\Delta\text{FRA}_{\text{stat}} = X - \text{FRA}_{\text{stat}}$ reported in Tables 4 and 5 is the one used in the right panel of Figure 4.

Figure 4 visualizes the relationship for all 103 countries. The left panel measures required increases from a uniform age-65 baseline, while the right panel measures increases from each country’s current statutory retirement age. In the left panel, Japan is the striking outlier at the bottom right: it has the highest 2024 OADR in the sample (54.9%) but among the smallest required increases (14 years), because much of its aging has already occurred. Hong Kong (OADR = 36.0%, 26 years) is the largest required increase among early-aging economies, while China and South Korea (both 24 years) and Singapore (25 years) cluster at the upper boundary among late-aging economies. The statutory-baseline measure tightens the negative relationship because it captures not only future demographic pressure but also how far current pension institutions remain from the age-65 benchmark. Countries with statutory ages well below 65—such as China (60), India (60), and Thailand (60)—face substantially larger required adjustments under this measure.

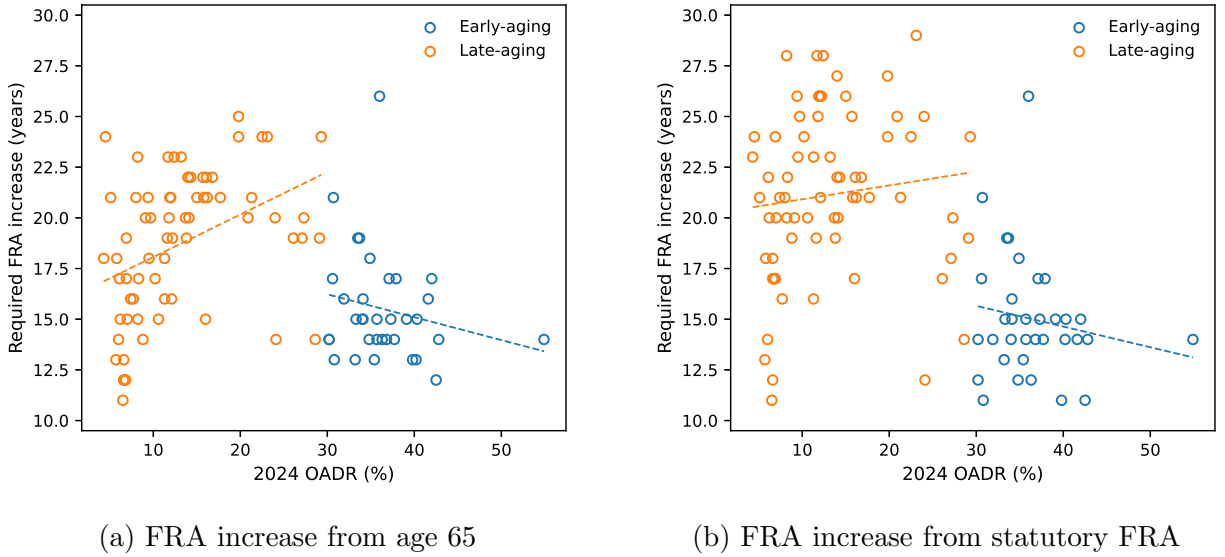


Figure 4: Old-Age Dependency Ratios and Required Retirement Age Increases

Notes: Each panel shows 2024 OADR ($65 + / 20-64$) and required full retirement age (FRA) increases for 103 countries. Panel (a) measures FRA increases from a uniform age-65 baseline (pooled $\rho = -0.24$; within groups, -0.20 early-aging and $+0.40$ late-aging). Panel (b) measures increases from each country’s current statutory FRA (pooled $\rho = -0.51$; -0.16 early, $+0.11$ late). Blue circles: early-aging economies ($N = 34$); orange circles: late-aging economies ($N = 69$). Dashed lines show OLS fits. Data: UN World Population Prospects 2024, OECD *Pensions at a Glance* 2024, and national legislation.

3.7 Cohort Momentum and the Limits of Fertility Policy

The retirement-boundary calculations of Section 3.6 raise an obvious question. If the required adjustments are as large as Tables 4 and 5 suggest, why not raise fertility instead? This subsection shows that, for the horizon over which the fiscal adjustment must occur, fertility is not an available instrument—and that in the near term a fertility recovery makes the dependency burden heavier rather than lighter.

The first point is arithmetic and requires no projection. Everyone aged 65 or over in year T was born no later than $T - 65$. A person turning 65 in 2100 was born in 2035; a person turning 65 in 2090 is alive in 2025. The numerator of the old-age dependency ratio is therefore essentially fixed for the remainder of this century in every economy in the sample. Fertility from today onward can move only the denominator, and only with a lag of at least twenty years before the additional cohorts reach working age.

The magnitude of that constraint is reported in the first two columns of Table 6, which give the share of the working-age population at each horizon born after 2026. This is an upper bound on the fraction of the future workforce that any fertility change beginning in 2027 could reach, not an estimate of what such a change would accomplish. For the late-aging economies the share is small at mid-century and rises only slowly thereafter.

The second point is that a fertility recovery is costly before it is beneficial. Additional children are dependents for roughly two decades before they are workers, so the total dependency ratio—which counts the young as well as the old—rises before it falls, and the working-age share falls before it rises. This mechanism is long established in the demographic and public-finance literatures. Cutler, Poterba, Sheiner, and Summers (1990) showed that a fertility decline reduces youth dependency and raises capital per worker, so that the net effect on living standards is far smaller than the old-age dependency ratio alone suggests. Lee, Mason, and members of the NTA Network (2014) use National Transfer Accounts data for forty countries to show that the fertility rate most favorable to government budgets lies well above replacement, while the rate most favorable to the material standard of living lies near or below it, once the cost of equipping a growing labor force with capital is taken into account. See also Striessnig and Lutz (2013) and, on the adaptation-versus-mitigation framing adopted below, Lutz (2007).

Columns three through six of Table 6 quantify the mechanism in the present setting by comparing the WPP low and medium variants, where the medium variant serves as the fertility recovery. In 2050 the medium variant delivers a *higher* total dependency ratio and a *lower* working-age share than the low variant in every economy in the table. The final column reports the first year in which the medium-variant working-age share overtakes the low-variant share. For the late-aging economies the crossover arrives well after the period over which the retirement-boundary adjustments of Section 3.6 would have to be legislated and phased in.

Table 6: Cohort momentum and the near-term cost of a fertility recovery

	Share of 20–64		Total dep. 2050		WA share 2050		Crossover
	2050	2075	Low	Medium	Low	Medium	year
<i>Early-aging</i>							
Japan	7%	62%	1.016	1.108	0.496	0.474	2066
Italy	7%	61%	0.975	1.063	0.506	0.485	2066
Spain	7%	62%	0.966	1.057	0.509	0.486	2067
United States	8%	65%	0.705	0.799	0.586	0.556	2080
<i>Late-aging</i>							
South Korea	5%	57%	0.932	1.018	0.518	0.495	2060
China	5%	51%	0.702	0.790	0.587	0.559	2064
Thailand	7%	61%	0.736	0.829	0.576	0.547	2068
Türkiye	7%	57%	0.638	0.731	0.610	0.578	2071
Brazil	8%	60%	0.642	0.737	0.609	0.576	2073
Chile	6%	56%	0.641	0.734	0.609	0.577	2065

Note: “Share of 20–64” is the fraction of the working-age population at the indicated year born after 2026, i.e. the largest fraction of the workforce that any fertility change beginning in 2027 could affect. It is an upper bound on reach, not an effect size, and is computed from the medium-variant age structure. The total dependency ratio is $(P_{0-19} + P_{65+})/P_{20-64}$ and the working-age share is P_{20-64}/P . “Crossover” is the first year after 2030 in which the medium-variant working-age share exceeds the low-variant share; — indicates no crossover before 2100. Source: WPP 2024.

Two implications follow. First, the choice of fertility variant, discussed in Appendix [B](#), matters far less for the fiscal results of this paper than for the long-run demographic ones: the variants differ negligibly before the 2050s and diverge substantially only in the second half of the century. Second, and more importantly, the margins of adjustment listed in Section [3.6](#)—later retirement, higher participation, capital deepening, broader taxation, immigration—share a property that fertility policy does not. Each operates on cohorts that are already alive. That is not an argument against family policy, which has its own and largely independent justification in helping households achieve their desired family size. It is an argument that family policy and fiscal adjustment address different horizons and are not substitutes for one another over any horizon relevant to the projections in this paper.

4 Aging in the Solow Growth Model

We project output, capital, and living standards for 103 countries from 2024 to 2100 using a Solow growth model in which the working-age population follows country-specific demographic paths from the United Nations World Population Prospects 2024 revision ([United Nations, Department of Economic and Social Affairs, Population Division \(2024\)](#)). The framework is intentionally simple. Because the goal is to isolate the quantitative contribution of demographic change and TFP-path assumptions to long-run growth, I abstract from endogenous saving, human capital accumulation, and general equilibrium interactions, and hold most non-demographic parameters fixed at their historically calibrated values.

The main specification uses the low-fertility population path; medium fertility is reported as an optimistic sensitivity in the appendix. The section has two main results. First, population aging lowers aggregate GDP growth through the decline in the working-age share. Second, for many late-aging middle-income countries, this demographic channel is compounded by a separate TFP-path channel. Countries that grew rapidly while catching up to the frontier, with the United States treated as the frontier economy, cannot maintain above-frontier TFP growth indefinitely. At the same time, countries with negative historical TFP growth are not assumed to experience permanent exponential decline; their TFP growth rates converge to zero. I use a Shapley decomposition to allocate the nonlinear interaction between demographics and TFP paths. The growth-accounting framework follows [Fernández-Villaverde, Ohanian, and Yao \(2026\)](#); the production function follows [Fernández-Villaverde, Ventura, and Yao \(2025\)](#) in using working-age population rather than total employment or hours as the labor input.

4.1 Production Technology

Each economy produces output according to a Cobb-Douglas aggregate production function,

$$Y_t = A_t K_t^\theta L_t^{1-\theta}, \quad (2)$$

where Y_t is real GDP, K_t is the aggregate capital stock, L_t is the working-age population (ages 20–64), A_t is total factor productivity, and $\theta \in (0, 1)$ is the capital share.

The capital stock evolves according to

$$K_{t+1} = (1 - \delta) K_t + s Y_t, \quad (3)$$

where δ is the depreciation rate of the capital stock and s is the investment rate (gross capital formation as a share of GDP). Both parameters are treated as fixed at their country-specific historical averages, as described in [Section 4.5](#).

4.2 Data

Real GDP at constant 2021 national prices (`rgdpna`), capital stock (`rnna`), labor share of income (`labsh`), depreciation rate (`delta`), and investment share (`csh_i`) are from Penn World Table 11.0 [Feenstra, Inklaar, and Timmer \(2015\)](#), which covers the period 1950–2023.⁸ Working-age (ages 20–64) and total population series are from the United Nations World Population Prospects 2024 [United Nations, Department of Economic and Social Affairs, Population Division \(2024\)](#), spanning 1950–2023 for historical estimates and 2024–2100 for projections under both the medium and low fertility scenarios. The 103 countries in our sample are listed in

⁸PWT 11.0, released in 2025, reports China on its official national accounts rather than the Maddison/Wu adjusted series used through version 10.01. China’s annualized per-capita growth over 1990–2020 is 8.14% on the current series against 5.61% on the earlier one, and its Solow residual over 1991–2019 rises correspondingly. We use the current vintage throughout and report the sensitivity of China’s drag decomposition to this choice in [Section 5.2](#). No other country in the sample is affected by a comparable methodological revision.

Tables 7 and 8; they span a wide range of demographic trajectories, and include both early-aging economies in which working-age populations are already contracting and late-aging economies in which they are still growing or have recently peaked but face steep declines after 2030–2050.

4.3 Counterfactuals and Shapley Decomposition

Demographic changes and TFP-path changes interact through capital accumulation, so their separate contributions cannot be measured cleanly by changing one assumption at a time in an arbitrary order. A declining working-age share lowers output directly, but it also lowers investment and therefore future capital accumulation and output. Similarly, a slower TFP path lowers output and investment, which changes the capital stock on which the demographic effect is measured. A sequential decomposition would assign this interaction mechanically to whichever channel is removed second.⁹ The Shapley decomposition (Shorrocks (2013)), which adapts the Shapley value of cooperative game theory (Shapley (1953)) to the attribution of an aggregate outcome among its determinants, avoids this order dependence by assigning each channel its average marginal contribution across the two possible orderings.¹⁰

The growth decomposition compares the baseline projection with counterfactual paths that remove either the change in age structure, the TFP-path transition, or both. The demographic counterfactual is designed to isolate the effect of a changing working-age share rather than the effect of total population size alone. Let $N_{i,t}$ denote total population and $L_{i,t}$ the working-age population for country i at time t . I define the 2024 working-age share as

$$\omega_{i,2024} = \frac{L_{i,2024}}{N_{i,2024}},$$

and construct a demographic counterfactual labor input

$$L_{i,t}^{\text{cf}} = \omega_{i,2024} N_{i,t}.$$

⁹In this application the interaction is economically negligible. Computing the two sequential decompositions—removing aging first, then removing the TFP transition first—and the Shapley average for representative countries shows that even for China, where it is largest, the orderings differ by only 0.07 pp per year (a demographic component ranging from -0.78 to -0.85 , with Shapley at the midpoint -0.81); for Korea and Poland the orderings differ by 0.01–0.02 pp, and for Japan, whose calibrated TFP growth is 0.33% and below the frontier rate so that the baseline embeds no TFP-path transition, the two orderings coincide exactly. The Shapley decomposition is the order-independent choice, but the demographic/TFP split does not hinge on it.

¹⁰The framework is that of Shorrocks (2013); it has recently been used to attribute structural-model counterfactuals to interacting components (Kwon, Lee, and Pouliot (2024)). Two alternatives are standard. The first is the classical growth-accounting practice of reporting each channel’s sequential effect alongside an explicit, unallocated interaction term; the Shapley rule instead splits that interaction symmetrically rather than assigning it by an arbitrary order. The second is a continuous-time (Divisia) decomposition that integrates instantaneous contributions along the transition path and is additive by construction; the two-factor Shapley average used here is its natural discrete-time counterpart. All three are order-independent, but the Shapley rule delivers an exact, residual-free split of the simulated paths without imposing a continuous-time approximation.

Thus, the counterfactual keeps the 2024 working-age share fixed while allowing total population to follow the WPP projection. This differs from freezing the absolute level of working-age population: it removes the aging-induced change in the age structure while preserving aggregate population growth or decline.

The TFP counterfactual removes the TFP-path transition. Let $\hat{g}_{A,i}$ be country i 's calibrated historical TFP growth rate and let g^* denote the U.S. frontier TFP growth rate, approximately 1.11% per year over 1991–2019. In the baseline, I assume that countries with $\hat{g}_{A,i} > g^*$ converge linearly to g^* by 2045.¹¹

Countries with $0 \leq \hat{g}_{A,i} \leq g^*$ remain on their historical TFP-growth path. Countries with $\hat{g}_{A,i} < 0$ are assumed to converge linearly to zero by 2045. The last case is a zero-growth floor that prevents the model from extrapolating negative TFP growth indefinitely. The corresponding no-transition counterfactual keeps each country at its own historical TFP growth rate throughout the projection.

Because the two channels interact through capital accumulation, a one-factor-at-a-time decomposition would depend on the order in which the channels are removed. I therefore define four average annual growth rates for each outcome $z \in \{Y, Y/N\}$: the baseline path, a path with demographic aging removed, a path with the TFP-path transition removed, and a path with both channels removed. Total drag is

$$D_{z,i}^{\text{total}} = g_{z,i}^{\text{base}} - g_{z,i}^{\text{no both}}.$$

The Shapley demographic component is

$$D_{z,i}^{\text{dem}} = \frac{1}{2} \left[\left(g_{z,i}^{\text{base}} - g_{z,i}^{\text{no aging}} \right) + \left(g_{z,i}^{\text{no TFP}} - g_{z,i}^{\text{no both}} \right) \right],$$

and the Shapley TFP-path component is

$$D_{z,i}^{\text{TFP}} = \frac{1}{2} \left[\left(g_{z,i}^{\text{base}} - g_{z,i}^{\text{no TFP}} \right) + \left(g_{z,i}^{\text{no aging}} - g_{z,i}^{\text{no both}} \right) \right].$$

By construction,

$$D_{z,i}^{\text{dem}} + D_{z,i}^{\text{TFP}} = D_{z,i}^{\text{total}}.$$

The averaging in these formulas is the two-factor Shapley value, and it has a simple interpretation. Each bracketed term is the *marginal contribution* of one channel, evaluated under a different assumption about the other channel. In $D_{z,i}^{\text{dem}}$, the first term, $g_{z,i}^{\text{base}} - g_{z,i}^{\text{no aging}}$, is the growth effect of demographic change measured while the TFP transition is switched *on*; the second term, $g_{z,i}^{\text{no TFP}} - g_{z,i}^{\text{no both}}$, is the same demographic effect measured while the TFP transition is switched *off*. These two marginal contributions are generally not equal, because output finances investment: the growth cost of a shrinking working-age share depends on how fast TFP—and hence output, saving, and capital accumulation—is growing along the path. A sequential decomposition would have to remove one channel first and the other second, and would assign the entire interaction between the channels to whichever channel is

¹¹The convergence date is a twenty-year horizon from the start of the projection, chosen so that the adjustment is gradual relative to the seventy-six-year projection window without being so slow that it dominates the later decades.

removed second; reversing the order would change both reported components. The Shapley decomposition removes each channel first in one ordering and second in the other, averages the two answers, and thereby splits the interaction term evenly. The result is exact, since the components sum to total drag, and independent of the order in which the channels are considered¹²

Negative values indicate that the channel lowers growth relative to the relevant counterfactual; positive values indicate a tailwind. The projection period is 2024–2100, but growth rates are computed from 2025 to 2100 because all paths are initialized to be identical in 2024. The example uses a deliberately large interaction to make the two orderings visibly different. In the calibrated results the interaction is far smaller—it never exceeds 0.067 percentage points—so the two orderings nearly coincide; Section 5.4 reports the bounds.

4.4 Analytical Benchmarks for the Simulated Drag

The Solow simulations include transitional capital accumulation, but the main demographic channel has a simple closed-form benchmark. With

$$Y_{i,t} = A_{i,t} K_{i,t}^{\theta_i} L_{i,t}^{1-\theta_i},$$

let $m_{i,t} = K_{i,t}/Y_{i,t}$ denote the capital-output ratio and $\omega_{i,t} = L_{i,t}/N_{i,t}$ the working-age share. Rearranging the production function gives

$$\frac{Y_{i,t}}{N_{i,t}} = A_{i,t}^{1/(1-\theta_i)} m_{i,t}^{\theta_i/(1-\theta_i)} \omega_{i,t}.$$

Average annual growth in output per capita over any horizon therefore satisfies

$$g_{Y/N,i} = \frac{1}{1-\theta_i} g_{A,i} + \frac{\theta_i}{1-\theta_i} g_{m,i} + g_{\omega,i},$$

where $g_{\omega,i}$ is the average growth rate of the working-age share and $g_{m,i}$ is the average growth rate of the capital-output ratio. Since the demographic counterfactual holds $\omega_{i,t}$ fixed at its 2024 value while leaving total population on the same WPP path, the closed-form demographic-drag benchmark is

$$\tilde{D}_i^{dem} = g_{\omega,i} = \frac{1}{T} [\log(\omega_{i,2100}) - \log(\omega_{i,2024})],$$

¹²A stylized example makes the averaging concrete. Suppose, in percent per year, $g^{\text{base}} = 1.0$, $g^{\text{no aging}} = 1.5$, $g^{\text{no TFP}} = 3.0$, and $g^{\text{no both}} = 3.8$, so total drag is $1.0 - 3.8 = -2.8$ pp. Removing aging first attributes $1.0 - 1.5 = -0.5$ pp to demographics and the remaining $1.5 - 3.8 = -2.3$ pp to the TFP transition; removing the TFP transition first attributes $1.0 - 3.0 = -2.0$ pp to the TFP transition and the remaining $3.0 - 3.8 = -0.8$ pp to demographics. Both orderings sum to -2.8 pp but disagree on the split because of the 0.3 pp interaction. The Shapley components average the two orderings:

$$D^{\text{dem}} = \frac{1}{2}(-0.5 - 0.8) = -0.65 \quad \text{and} \quad D^{\text{TFP}} = \frac{1}{2}(-2.0 - 2.3) = -2.15,$$

which again sum to -2.8 pp. The Shapley decomposition columns in Tables 7–12 are constructed in this way; for example, China’s demographic component of -0.813 pp and TFP-path component of -3.415 pp in Table 12 sum exactly to its total per-capita drag of -4.228 pp.

where T is the length of the projection horizon. If the capital-output ratio were stable and identical across the baseline and no-aging paths, this expression would be the entire demographic growth effect. More generally, the simulated demographic component can be written approximately as

$$D_{Y/N,i}^{dem} \approx g_{\omega,i} + \frac{\theta_i}{1 - \theta_i} (g_{m,i}^{base} - g_{m,i}^{no\ aging}).$$

Thus, the gap between the simulated demographic component and the closed-form working-age-share benchmark measures the transitional capital-accumulation term. The same logic also explains why the demographic component for aggregate GDP and GDP per capita are nearly identical: the no-aging counterfactual changes the working-age share but not the total population path, so aggregate population growth cancels in the comparison.

A parallel benchmark applies to the TFP-normalization component. Let $\hat{g}_{A,i}$ be country i 's historical TFP growth rate and $\bar{g}_{A,i}^{base}$ the average TFP growth rate along the baseline transition path. Holding the capital-output ratio fixed, the TFP-normalization effect is approximately

$$\tilde{D}_i^{TFP} = \frac{\bar{g}_{A,i}^{base} - \hat{g}_{A,i}}{1 - \theta_i}.$$

For countries with $\hat{g}_{A,i} > g^*$, baseline TFP growth converges linearly from $\hat{g}_{A,i}$ to the frontier rate g^* by 2045 and remains at g^* thereafter. If T is the full projection horizon and T_c is the convergence period, this implies

$$\tilde{D}_i^{TFP} = \frac{T - T_c/2}{T} \frac{g^* - \hat{g}_{A,i}}{1 - \theta_i}.$$

For countries with $\hat{g}_{A,i} < 0$, the same expression applies with $g^* = 0$, so the TFP-normalization component is positive: the zero-growth floor creates a tailwind relative to a counterfactual that extrapolates negative historical TFP growth through 2100. Comparing these analytical benchmarks with the simulated Shapley components provides a diagnostic for the role of transitional capital accumulation.

4.5 Calibration

All structural parameters are calibrated using the 1991–2019 period from Penn World Table 11.0 [Feenstra, Inklaar, and Timmer \(2015\)](#). For each country i , we compute

$$\hat{\delta}_i = \overline{\text{delta}_i}_{1991-2019}, \quad (4)$$

$$\hat{\theta}_i = 1 - \overline{\text{labsh}_i}_{1991-2019}, \quad (5)$$

$$\hat{s}_i = \overline{\text{csh_i}_i}_{1991-2019}, \quad (6)$$

where overbars denote sample means and `delta`, `labsh`, and `csh_i` are PWT 11.0 variables for the average depreciation rate, the labor compensation share of GDP at current national

prices, and the share of gross capital formation in GDP, respectively¹³. To guard against outliers in the labor share—which can arise from measurement error in countries with large self-employment sectors—we winsorize $\hat{\theta}_i$ to the interval $[0.25, 0.65]$.

The 2023 capital stock $K_{i,2023}$ is taken directly from the PWT variable `rnna` (capital stock at constant 2021 national prices). The initial TFP level is recovered as

$$A_{i,2023} = \frac{Y_{i,2023}}{K_{i,2023}^{\hat{\theta}_i} L_{i,2023}^{1-\hat{\theta}_i}}, \quad (7)$$

where $Y_{i,2023}$ is PWT `rgdpna` and $L_{i,2023}$ is the working-age population in 2023 from the WPP estimates. The historical TFP growth rate $\hat{g}_{A,i}$ is computed as the average annual growth rate of $A_{i,t}$ over 1991–2019¹⁴.

A caveat about the TFP measure is in order, and it bears directly on how the decomposition should be read. Historical TFP growth $\hat{g}_{A,i}$ is computed as a Solow residual, $\log A = \log Y - \theta \log K - (1 - \theta) \log L$, with working-age population as the labor input L . Any effect of population age structure on measured productivity—through the age composition of the workforce, through the accumulation of experience, or through the effect of aging on innovation—is therefore absorbed into $\hat{g}_{A,i}$ rather than isolated from it. Two implications follow. First, the demographic component reported below should be read as a *lower bound* on the total effect of aging on growth: it captures the mechanical consequence of a changing working-age share, holding the TFP path fixed, and excludes any effect operating through productivity itself. Second, if aging does depress TFP growth, then part of what is labelled here as the TFP-path component is demographic in origin. The Shapley split is accordingly an accounting decomposition of a simulated growth path, not a causal attribution of growth to two independent forces. Hayashi (2026) estimates precisely the channel this framework holds fixed—a negative effect of the old-to-young ratio on TFP growth among post-transitional economies—and finds it large. Read together, the two approaches bracket the effect of aging on growth: the accounting component from below, the estimated reduced-form channel from above.

4.6 Numerical Results

Before turning to results, it is useful to spell out the mechanics of the numerical exercise. Each country’s projection is initialized at a common 2024 starting point: the 2024 capital stock follows from the perpetual-inventory equation (3) applied to the 2023 PWT capital stock and output, $K_{2024} = (1 - \hat{\delta})K_{2023} + \hat{s}Y_{2023}$; the 2024 TFP level follows from the recovered A_{2023} of equation (7) grown along the country’s TFP path; and L_{2024} is the WPP working-age population. Output in 2024, $Y_{2024} = A_{2024}K_{2024}^{\hat{\theta}}L_{2024}^{1-\hat{\theta}}$, is therefore identical across the baseline and all counterfactuals. From there the model iterates forward

¹³The baseline calibration takes the time-series average of the current-price share of gross capital formation and applies it to constant-price real GDP. In a stylized one-sector Solow model, this is a standard macroeconomic approximation used to capture an economy’s aggregate saving effort. By adopting this one-good abstraction, the framework intentionally abstracts from historical changes in the relative prices of investment goods versus consumption goods.

¹⁴Table 22 in the Appendix reports the calibrated parameters for all 103 economies.

one year at a time. Investment out of 2024 output determines the next year’s capital stock, $K_{2025} = (1 - \hat{\delta})K_{2024} + \hat{s}Y_{2024}$; combined with the 2025 working-age population from the relevant WPP variant and with A_{2025} grown along the convergence schedule of Section 4.3—linearly toward g^* by 2045 for above-frontier economies, at the historical rate $\hat{g}_A$ for economies with $\hat{g}_A \in [0, g^*]$, and linearly toward zero by 2045 for economies with negative historical TFP growth—it delivers $Y_{2025} = A_{2025}K_{2025}^{\hat{\theta}}L_{2025}^{1-\hat{\theta}}$, and so on through 2100. The four scenarios of Section 4.3 differ only in the labor input L_t (baseline WPP path versus the fixed-share counterfactual $L_t^{\text{cf}} = \omega_{2024}N_t$) and in the growth path of A_t (convergence schedule versus the no-transition path); the parameters $\hat{\theta}$, $\hat{\delta}$, $\hat{s}$ and the 2024 initial conditions are common to all four. The growth rates entering the drag formulas are the averages of the 75 annual log growth rates for 2025–2100, equivalently $g_{z,i} = \frac{100}{75} \ln(z_{i,2100}/z_{i,2025})$ for $z \in \{Y, Y/N\}$; because all scenarios share identical 2024 values, each drag—the difference between two such growth rates, in percentage points per year—depends only on the divergence of the paths from 2025 onward.

The results can be organized into three broad groups. For most frontier and near-frontier economies, historical TFP growth is below the U.S. frontier rate and nonnegative, so the TFP-path component is zero and total drag is dominated by the demographic channel. For fast-converging middle-income economies with recent TFP growth above the frontier rate, the convergence of TFP growth to the frontier creates an additional TFP-path headwind that can be as large as, or larger than, the demographic component. Finally, for economies with negative historical TFP growth, the zero-growth floor creates a TFP-path tailwind because the baseline improves relative to a counterfactual that extrapolates negative TFP growth through 2100. These three cases provide a useful roadmap for interpreting the country-level tables below.

Demographic drag is negative for most of the 103 countries, confirming that population aging exerts a growth headwind across the sample. Exceptions arise among high-fertility Sub-Saharan African and South Asian economies—Ethiopia, Ghana, Uganda, Pakistan, and Cambodia—where working-age populations continue growing fast enough to generate a demographic tailwind under the corrected capital-share calibration. Among economies with negative drag, it ranges from -0.06 percentage points (Myanmar, medium fertility) to -0.815 percentage points (South Korea, low fertility), with the full-sample median of -0.17 percentage points under medium fertility and -0.24 percentage points under low fertility.

Table 7: Demographic Drag Decomposition, 2024–2100: Early-Aging Economies

Country	g_Y	g_N	Dem. drag	Country	g_Y	g_N	Dem. drag
Japan	-0.43	-1.10	-0.292	Belgium	0.35	-0.52	-0.238
Finland	0.89	-0.71	-0.216	Hungary	0.73	-0.82	-0.217
Portugal	-0.11	-0.67	-0.225	Spain	-0.33	-0.96	-0.397
Italy	-1.16	-1.17	-0.341	Netherlands	1.05	-0.51	-0.267
Greece	-0.63	-1.10	-0.275	Austria	0.23	-0.73	-0.316
Croatia	0.08	-1.32	-0.355	Romania	0.24	-1.34	-0.308
France	0.67	-0.40	-0.174	United Kingdom	0.93	-0.34	-0.202
Germany	0.59	-0.68	-0.240	Poland	0.42	-1.47	-0.498
Serbia	-0.30	-1.36	-0.331	Lithuania	0.08	-1.77	-0.463
Latvia	0.31	-1.51	-0.314	Switzerland	0.18	-0.38	-0.295
Bulgaria	-1.99	-1.44	-0.250	Canada	1.05	0.03	-0.207
Slovenia	0.69	-0.80	-0.274	Norway	0.47	-0.49	-0.257
Estonia	0.51	-1.17	-0.326	USA	1.73	-0.15	-0.161
Sweden	1.35	-0.33	-0.201	Ukraine	-2.37	-1.86	-0.456
Denmark	0.73	-0.48	-0.225	Slovakia	0.80	-1.15	-0.367
Hong Kong	-0.91	-2.24	-1.270	Australia	2.00	0.20	-0.162
Czechia	1.05	-0.83	-0.224	New Zealand	2.17	0.20	-0.157
Mean	+0.33	-0.86	-0.309				

Notes: UN WPP 2024 **low** fertility. g_Y = baseline average annual aggregate GDP growth rate, 2025–2100; g_N = baseline average annual total population growth rate; baseline per-capita growth is recoverable as $g_{Y/N} \approx g_Y - g_N$. Dem. drag = Shapley demographic component $D_{Y/N,i}^{\text{dem}}$ of Section 4.3, in percentage points per year. Because the demographic counterfactual holds the 2024 working-age share fixed while total population follows the same WPP path, the demographic component is identical for aggregate and per-capita growth ($D_{Y,i}^{\text{dem}} = D_{Y/N,i}^{\text{dem}}$), so a single drag column suffices. Negative = headwind; positive = tailwind. $N = 34$; sorted by 2024 OADR (descending).

The broader 103-country sample reveals interesting geographic patterns. Several post-Soviet economies (Russia, Ukraine, Latvia, Bulgaria) show relatively small negative per-capita drag (−0.146 pp for Russia, −0.456 pp for Ukraine) despite large negative baseline aggregate GDP growth, because shrinking total populations lower the denominator, partially offsetting the working-age decline. Romania (−0.308 pp) and Poland (−0.498 pp) face substantial per-capita headwinds. The severe fertility collapses of the 1990s are most visible in low baseline aggregate GDP growth: Ukraine ($g_Y = -2.37\%/yr$) and Poland ($g_Y = +0.42\%/yr$) with $g_N = -1.47\%/yr$ face large economy-wide output headwinds.

Table 8: Demographic Drag Decomposition, 2024–2100: Late-Aging Economies

Country	g_Y	g_N	Dem. drag	Country	g_Y	g_N	Dem. drag
South Korea	0.03	-1.72	-0.815	Bangladesh	0.53	-0.33	-0.125
Belarus	-0.10	-1.58	-0.390	Paraguay	1.10	-0.20	-0.060
Russia	0.59	-0.66	-0.146	South Africa	0.66	0.01	-0.012
Uruguay	0.96	-1.11	-0.364	Cambodia	0.45	-0.24	0.013
Ireland	2.23	-0.47	-0.283	Uzbekistan	-0.74	0.48	0.023
Iceland	0.90	-0.58	-0.368	Bolivia	1.23	-0.07	0.039
Israel	2.64	0.59	0.028	Philippines	0.83	-0.63	-0.051
Thailand	0.45	-1.13	-0.426	Egypt	1.88	0.23	0.068
China	0.34	-1.65	-0.813	Mongolia	3.05	0.12	0.012
Chile	0.79	-1.05	-0.514	Guatemala	0.61	-0.11	0.019
Argentina	0.24	-0.78	-0.228	Pakistan	3.06	0.43	0.250
Sri Lanka	0.83	-0.66	-0.244	Rwanda	2.52	0.64	0.254
Singapore	1.58	-0.95	-0.610	Jordan	1.93	0.36	-0.020
Costa Rica	-0.26	-0.93	-0.537	Zimbabwe	1.63	0.53	0.353
Brazil	-0.95	-0.91	-0.348	Honduras	0.00	0.07	-0.034
Türkiye	-0.47	-0.95	-0.364	Senegal	0.89	0.77	0.226
Panama	-0.15	-0.13	-0.162	Ghana	4.26	0.39	0.196
Tunisia	1.14	-0.74	-0.310	Tanzania	3.40	1.35	0.349
Kazakhstan	2.58	0.19	0.011	Ethiopia	3.79	0.90	0.271
Peru	1.12	-0.37	-0.213	Iraq	4.80	0.54	0.193
Colombia	0.73	-0.70	-0.365	Nigeria	2.60	0.48	0.358
Viet Nam	-0.20	-0.68	-0.201	Angola	4.10	1.39	0.398
Ecuador	1.13	-0.47	-0.248	Sudan	2.37	0.41	0.411
Morocco	0.86	-0.58	-0.196	Niger	3.73	1.18	0.525
Mexico	-0.02	-0.58	-0.161	Mozambique	2.95	0.96	0.470
El Salvador	-1.28	-0.95	-0.240	Mali	5.12	1.26	0.509
Dominican Rep.	1.48	-0.55	-0.133	Cameroon	1.89	1.02	0.352
Azerbaijan	-2.45	-0.56	-0.136	Kenya	0.73	0.26	0.255
Iran	-0.57	-0.71	-0.305	Burkina Faso	2.80	0.48	0.404
Malaysia	1.07	-0.19	-0.205	Malawi	6.22	0.82	0.352
Indonesia	0.47	-0.49	-0.128	Côte d'Ivoire	2.72	1.13	0.318
Myanmar	-1.73	-0.74	-0.072	Uganda	1.81	0.65	0.335
India	1.60	-0.50	-0.224	Saudi Arabia	0.18	0.59	-0.020
Algeria	0.92	-0.05	-0.059	Zambia	3.79	0.98	0.326
Nepal	0.61	-0.54	-0.035				
<i>Mean</i>	+1.36	-0.10	-0.041				

Notes: UN WPP 2024 **low** fertility. See Table 7 for column definitions. $N = 69$; sorted by 2024 OADR (descending).

Sub-Saharan Africa presents a qualitatively different picture. Many African economies exhibit positive demographic drag—a tailwind—because their working-age populations continue growing robustly. Ethiopia (+0.24 pp medium, +0.27 pp low), Ghana (+0.16, +0.20), and Uganda (+0.31, +0.34) all show net demographic benefits under the corrected capital-share calibration. However, this dividend is temporary: these countries’ challenge is not imminent working-age decline but the long-run trajectory of aging that begins in earnest after 2060. Nigeria, with a demographic tailwind of +0.31 pp (medium) and +0.36 pp (low), illustrates the eventual transition. Crucially, these countries will be navigating their demographic transitions with far weaker fiscal institutions, lower per-capita incomes, and less-developed pension systems than any previous wave of aging economies—a distinct “third wave” fiscal challenge.

Middle Eastern economies cluster around -0.20 to -0.30 pp under medium fertility, with Iran (-0.28 pp) and Egypt (-0.22 pp) facing pressures comparable to major advanced economies. These countries completed rapid fertility transitions in the 1990s–2010s and

are now experiencing the downstream consequence: rapidly rising old-age dependency ratios from very low bases. Iran’s fertility decline from 5.5 in 1985 to approximately 1.6 today rivals any historical transition in its speed, and the working-age cohort effects will compound after 2040.

Early-aging economies exhibit generally larger drag magnitudes (median: -0.18 pp under medium fertility, -0.27 pp under low) compared to late-aging economies (median: -0.15 pp under medium, -0.22 pp under low). This pattern reflects the fact that early-agers are already deep into their demographic transition: their working-age shares are declining throughout the 2024–2100 projection window, generating persistent headwinds. Late-aging economies, by contrast, still have growing or recently-peaked working-age populations in 2024, with many Sub-Saharan African and South Asian economies contributing positive demographic tailwinds that pull the late-aging median toward zero.

China illustrates this dynamic most dramatically. Despite a moderate 2024 OADR, China faces a per-capita drag of -0.813 pp under low fertility—among the highest globally. The OADR rises from 23.1% in 2024 to 206.8% by 2100 under low fertility, the legacy of the one-child policy creating an unprecedented demographic cliff. South Korea faces -0.815 pp under low fertility. Moving from medium to low fertility raises China’s per-capita drag by approximately 33 basis points and South Korea’s by approximately 29 basis points—moderate increments that reflect the anchoring of both scenarios to the same 2024 OADR baseline.

Tables 9 and 10 report, for each economy whose calibrated TFP growth $\hat{g}_{A,i}$ exceeds the frontier rate $g^* = 1.11\%$, the annual Shapley TFP-path component under the low- and medium-fertility baselines, together with the calibrated TFP growth rate. Because the component applies identically to aggregate and per-capita growth and is nearly invariant to the fertility variant, two columns of drag values suffice.

The no-transition TFP path should not be read as a literal forecast. It is a benchmark that measures the contribution of imposing long-run convergence on economies whose recent TFP growth exceeded the frontier rate. For fast-growing economies such as China ($\hat{g}_A = 3.84\%$) or Iraq ($\hat{g}_A = 4.24\%$), the counterfactual path is deliberately demanding—sustaining recent above-frontier productivity growth through 2100. The resulting TFP-path component is therefore best interpreted as the growth contribution of ruling out indefinite above-frontier catch-up growth, not as a forecast of actual TFP slowdown. At the opposite end of the distribution, fourteen economies have *negative* historical TFP growth and converge upward to zero by 2045; Appendix Table 21 lists them with their calibrated rates and the resulting convergence tailwinds.

Table 9 covers the 14 above-frontier early-aging economies. Japan is *absent*: its $\hat{g}_A = 0.33\%$ is well below g^* , so it faces no negative TFP-path component and its total drag equals only its demographic component (-0.292 pp/yr). Poland carries the largest TFP-path component in the early-aging group at -1.264 pp/yr ($\hat{g}_A = 2.167\%$), nearly double the frontier rate. Slovakia (-1.126 pp/yr), Czechia (-0.930 pp/yr), Estonia (-0.744 pp/yr), and Slovenia (-0.722 pp/yr) follow. The Netherlands, barely above the frontier ($\hat{g}_A = 1.1066\%$ vs $g^* = 1.1061\%$), carries only -0.001 pp/yr.

Table 10 covers 22 above-frontier late-aging economies. Iraq records the largest single TFP-path component in the entire 103-country sample at -5.798 pp/yr ($\hat{g}_A = 4.237\%$). China faces -3.415 pp/yr ($\hat{g}_A = 3.838\%$), the largest among late-agers. Nige-

ria (-2.238 pp/yr), Mongolia (-2.193 pp/yr), and Kazakhstan (-1.562 pp/yr) also carry large TFP headwinds. Korea faces -0.394 pp/yr ($\hat{g}_A = 1.421\%$)—roughly half its demographic drag (-0.815 pp/yr), making it an economy where both channels impose large but unequal burdens. Relative to Japan (no negative TFP-path component), Korea’s combined exposure illustrates how faster historical catch-up amplifies the convergence penalty.

Table 9: Shapley TFP-Path Component of Growth Drag, 2024–2100: Early-Aging Economies

Country	Low	Med	$\hat{g}_A$ (%)	Country	Low	Med	$\hat{g}_A$ (%)
Finland	−0.026	−0.027	1.1284	Hungary	−0.489	−0.496	1.5269
Croatia	−0.363	−0.368	1.4282	Netherlands	−0.001	−0.001	1.1066
Latvia	−0.617	−0.630	1.6459	Romania	−0.274	−0.278	1.2982
Slovenia	−0.722	−0.730	1.7567	Poland	−1.264	−1.281	2.1674
Estonia	−0.744	−0.755	1.7374	Lithuania	−0.330	−0.338	1.3793
Sweden	−0.265	−0.268	1.3310	Slovakia	−1.126	−1.143	1.9629
Czechia	−0.930	−0.943	1.8200	Australia	−0.028	−0.028	1.1293

Notes: Shapley TFP-path component $D_{Y/N,i}^{\text{TFP}}$ of Section 4.3, pp/yr, under the WPP 2024 low (Low) and medium (Med) fertility baselines. $N = 14$ above-frontier early-agers ($\hat{g}_{A,i} > g^* = 1.11\%$). The component is nearly invariant across variants because the TFP convergence schedule depends only on calibrated historical TFP growth; differences below 0.05 pp/yr reflect the Shapley interaction with capital accumulation. The set of above-frontier economies is identical under both variants.

Table 10: Shapley TFP-Path Component of Growth Drag, 2024–2100: Late-Aging Economies

Country	Low	Med	$\hat{g}_A$ (%)	Country	Low	Med	$\hat{g}_A$ (%)
South Korea	−0.394	−0.401	1.4209	India	−1.175	−1.189	2.0272
Belarus	−0.154	−0.157	1.2368	Mongolia	−2.193	−2.220	2.4540
Uruguay	−0.490	−0.499	1.4979	Rwanda	−1.117	−1.122	2.1510
Ireland	−1.148	−1.162	1.9294	Ghana	−1.150	−1.161	1.7419
Iceland	−0.298	−0.302	1.3735	Iraq	−5.798	−5.849	4.2366
China	−3.415	−3.464	3.8377	Nigeria	−2.238	−2.269	2.5189
Singapore	−0.031	−0.032	1.1276	Sudan	−0.286	−0.288	1.3657
Tunisia	−0.386	−0.392	1.3992	Niger	−0.703	−0.709	1.6026
Kazakhstan	−1.562	−1.578	2.1843	Mali	−2.809	−2.826	2.5799
Ecuador	−0.035	−0.035	1.1332	Malawi	−1.877	−1.893	2.1080
Dominican Rep.	−0.901	−0.915	1.8001	Zambia	−1.033	−1.044	1.7721

Notes: Shapley TFP-path component $D_{Y/N,i}^{\text{TFP}}$ of Section 4.3, pp/yr, under the WPP 2024 low (Low) and medium (Med) fertility baselines. $N = 22$ above-frontier late-agers ($\hat{g}_{A,i} > g^* = 1.11\%$). The component is nearly invariant across variants because the TFP convergence schedule depends only on calibrated historical TFP growth; differences below 0.05 pp/yr reflect the Shapley interaction with capital accumulation. The set of above-frontier economies is identical under both variants.

Tables 11 and 12 combine both channels into a single summary under the low-fertility scenario, reporting for each economy the Shapley demographic drag, the TFP-path component, and total drag, all on $g_{Y/N}$. Under the fixed-working-age-share demographic counterfactual, total population is identical in baseline and counterfactual, so the Shapley aggregate-GDP drag equals the per-capita drag; aggregate baseline growth g_Y is separately available in Tables 7 and 8. Table 11 covers the 34 early-aging economies. For the majority of early-agers—Japan (-0.292 pp), Germany (-0.240 pp), France (-0.174 pp), and most of Western

Europe—TFP growth lies in the interval $[0, g^*]$, so the no-transition TFP path is identical to the baseline and the TFP-path component is zero: total per-capita drag equals demographic drag and ranges roughly -0.157 to -0.397 pp. A separate pattern arises for economies with historically *negative* TFP growth: Bulgaria, Italy, and Ukraine carry positive TFP-path components (tailwinds) because the baseline’s convergence to zero improves on the no-transition counterfactual’s permanently negative productivity path. These tailwinds partially offset the demographic headwind in total per-capita drag. A distinct sub-group of post-Soviet early-agers that began the sample period well below the frontier face both channels simultaneously and carry the largest total burdens: Poland (-1.762 pp/yr total per-capita: demographic -0.498 , TFP -1.264 pp), Slovakia (-1.493 pp/yr), Czechia (-1.153 pp/yr), Slovenia (-0.996 pp/yr), and Estonia (-1.070 pp/yr). Latvia and Lithuania, despite smaller demographic drags (-0.314 and -0.463 pp respectively), face large total per-capita burdens (-0.931 and -0.793 pp) because their TFP convergence costs are substantial. Hong Kong’s total per-capita drag equals its demographic drag (-1.270 pp), since its TFP growth is at or below the frontier and there is no TFP transition component. Relative to Japan (-0.292 pp total), Hong Kong’s situation is dramatically more severe despite its lower OADR, purely because of its steep projected dependency-ratio trajectory.

Table 11: Total Growth Drag, 2024–2100: Early-Aging Economies

Country	Dem Y/N	TFP Y/N	Total Y/N	Country	Dem Y/N	TFP Y/N	Total Y/N
Japan	-0.292	0.000	-0.292	Belgium	-0.238	0.000	-0.238
Finland	-0.216	-0.026	-0.243	Hungary	-0.217	-0.489	-0.706
Portugal	-0.225	0.000	-0.225	Spain	-0.397	0.000	-0.397
Italy	-0.341	0.108	-0.234	Netherlands	-0.267	-0.001	-0.268
Greece	-0.275	0.000	-0.275	Austria	-0.316	0.000	-0.316
Croatia	-0.355	-0.363	-0.717	Romania	-0.308	-0.274	-0.582
France	-0.174	0.000	-0.174	United Kingdom	-0.202	0.000	-0.202
Germany	-0.240	0.000	-0.240	Poland	-0.498	-1.264	-1.762
Serbia	-0.331	0.000	-0.331	Lithuania	-0.463	-0.330	-0.793
Latvia	-0.314	-0.617	-0.931	Switzerland	-0.295	0.000	-0.295
Bulgaria	-0.250	2.314	2.064	Canada	-0.207	0.000	-0.207
Slovenia	-0.274	-0.722	-0.996	Norway	-0.257	0.000	-0.257
Estonia	-0.326	-0.744	-1.070	USA	-0.161	0.000	-0.161
Sweden	-0.201	-0.265	-0.466	Ukraine	-0.456	0.653	0.198
Denmark	-0.225	0.000	-0.225	Slovakia	-0.367	-1.126	-1.493
Hong Kong	-1.270	0.000	-1.270	Australia	-0.162	-0.028	-0.190
Czechia	-0.224	-0.930	-1.153	New Zealand	-0.157	0.000	-0.157
Mean	-0.309	-0.121	-0.430				

Notes: Low fertility, UN WPP 2024. Dem. Y/N = Shapley demographic drag on per-capita growth. TFP Y/N = Shapley TFP-path component (above-frontier TFP converges to $g^* = 1.11\%$ by 2045; below-zero TFP converges to zero, generating a positive component). Total Y/N = sum of both Shapley components on per-capita GDP. Under the fixed-working-age-share counterfactual, aggregate and per-capita Shapley drag are equal; baseline aggregate GDP growth g_Y is reported separately in Table [12](#). Negative = headwind; positive = tailwind. $N = 34$; sorted by 2024 OADR (descending).

Table [12](#) covers the 69 late-aging economies and shows a qualitatively different pattern. China faces the largest total per-capita drag among late-aging economies: -4.228 pp/yr, combining a demographic component of -0.813 pp/yr with a TFP-path component of -3.415 pp/yr. Korea also faces large pressure on both margins, with total per-capita drag of -1.208 pp/yr (-0.815 pp demographic plus -0.394 pp TFP-path component), but several other late-aging economies have larger total per-capita drags because of the TFP-

path component: Kazakhstan (-1.550), Ireland (-1.431), and India (-1.400). Iraq records both the largest TFP-path component (-5.798 pp/yr) and the largest total per-capita drag of any country (-5.606 pp/yr) owing to its exceptional historical TFP growth rate, but it is not representative of the broader late-aging group. At the other end, economies such as Pakistan, Uganda, and Ethiopia have positive demographic tailwinds and no negative TFP-path component, so their total per-capita drag is close to zero or positive. The decomposition therefore separates two challenges: a demographic problem concentrated in rapidly aging economies such as Korea, Singapore, and China, and a TFP-transition problem concentrated in fast-catching-up economies such as China, India, Kazakhstan, and Ireland. The two problems coincide most clearly in China and Korea, which face headwinds from both channels simultaneously.

Table 12: Total Growth Drag, 2024–2100: Late-Aging Economies

Country	Dem Y/N	TFP Y/N	Total Y/N	Country	Dem Y/N	TFP Y/N	Total Y/N
South Korea	-0.815	-0.394	-1.208	Bangladesh	-0.125	0.000	-0.125
Belarus	-0.390	-0.154	-0.544	Paraguay	-0.060	0.000	-0.060
Russia	-0.146	0.000	-0.146	South Africa	-0.012	0.000	-0.012
Uruguay	-0.364	-0.490	-0.854	Cambodia	0.013	0.000	0.013
Ireland	-0.283	-1.148	-1.431	Uzbekistan	0.023	1.647	1.670
Iceland	-0.368	-0.298	-0.667	Bolivia	0.039	0.000	0.039
Israel	0.028	0.000	0.028	Philippines	-0.051	0.000	-0.051
Thailand	-0.426	0.000	-0.426	Egypt	0.068	0.000	0.068
China	-0.813	-3.415	-4.228	Mongolia	0.012	-2.193	-2.181
Chile	-0.514	0.000	-0.514	Guatemala	0.019	0.000	0.019
Argentina	-0.228	0.000	-0.228	Pakistan	0.250	0.000	0.250
Sri Lanka	-0.244	0.000	-0.244	Rwanda	0.254	-1.117	-0.863
Singapore	-0.610	-0.031	-0.641	Jordan	-0.020	0.000	-0.020
Costa Rica	-0.537	0.000	-0.537	Zimbabwe	0.353	0.000	0.353
Brazil	-0.348	0.000	-0.348	Honduras	-0.034	0.115	0.081
Türkiye	-0.364	0.255	-0.109	Senegal	0.226	0.000	0.226
Panama	-0.162	0.109	-0.053	Ghana	0.196	-1.150	-0.954
Tunisia	-0.310	-0.386	-0.696	Tanzania	0.349	0.000	0.349
Kazakhstan	0.011	-1.562	-1.550	Ethiopia	0.271	0.000	0.271
Peru	-0.213	0.000	-0.213	Iraq	0.193	-5.798	-5.606
Colombia	-0.365	0.000	-0.365	Nigeria	0.358	-2.238	-1.880
Viet Nam	-0.201	0.464	0.263	Angola	0.398	0.000	0.398
Ecuador	-0.248	-0.035	-0.283	Sudan	0.411	-0.286	0.125
Morocco	-0.196	0.000	-0.196	Niger	0.525	-0.703	-0.178
Mexico	-0.161	0.373	0.212	Mozambique	0.470	0.000	0.470
El Salvador	-0.240	0.000	-0.240	Mali	0.509	-2.809	-2.300
Dominican Rep.	-0.133	-0.901	-1.034	Cameroon	0.352	0.000	0.352
Azerbaijan	-0.136	7.513	7.377	Kenya	0.255	0.178	0.433
Iran	-0.305	0.000	-0.305	Burkina Faso	0.404	0.000	0.404
Malaysia	-0.205	0.000	-0.205	Malawi	0.352	-1.877	-1.525
Indonesia	-0.128	0.000	-0.128	Côte d'Ivoire	0.318	0.000	0.318
Myanmar	-0.072	1.499	1.426	Uganda	0.335	0.000	0.335
India	-0.224	-1.175	-1.400	Saudi Arabia	-0.020	3.163	3.142
Algeria	-0.059	0.094	0.035	Zambia	0.326	-1.033	-0.707
Nepal	-0.035	0.000	-0.035				
Mean	-0.041	-0.200	-0.241				

Notes: Low fertility, UN WPP 2024. Dem. Y/N = Shapley demographic drag on per-capita growth. TFP Y/N = Shapley TFP-path component. Total Y/N = sum of both Shapley components on per-capita GDP. See Table [11](#) notes for the relationship to aggregate baseline growth. Negative = headwind; positive = tailwind. $N = 69$; sorted by 2024 OADR (descending).

4.7 Growth Drag and Fiscal Adjustment

The Solow growth results can now be compared with the fiscal adjustment measure from Section 3.6. The comparison should be interpreted as a correlation between two summary statistics, not as a causal effect of growth on retirement ages or vice versa. The FRA measure asks how much the retirement boundary would have to move in order to hold each country’s 2024 OADR fixed through 2100. The growth-drag measures ask how much projected aging and TFP-path transitions change growth relative to transparent counterfactuals. Both are driven by demographic structure, but they capture different margins of adjustment.

Two patterns are useful. First, aging speed is informative about fiscal urgency: countries that move from OADR 25% to 50% in fewer years require larger FRA postponements to stabilize the 2024 OADR. Second, the growth-drag measures are less tightly related to aging speed because they depend on the remaining decline in working-age population shares after 2024 and, for TFP-path component, on each country’s recent productivity growth. Thus the fiscal and growth results capture distinct margins of the demographic transition: China and Korea are severe cases on both margins, while some economies have large FRA adjustments but modest near-term Solow drag, and others have sizable TFP-path component even though their aging transition is less advanced.

The orthogonality result is useful for interpretation. Table 13 reports the correlations between compression speed and the fiscal and growth statistics. The speed measure for the critical OADR 25–50 percent range ($\rho = -0.69$) is strongly related to the required FRA increase: faster compression is associated with larger required retirement-age adjustments. By contrast, the same speed measure is nearly unrelated to aging drag ($\rho = 0.14$), TFP-path component ($\rho = 0.04$), or total drag ($\rho = 0.07$) in the Solow exercise. The earlier OADR 12.5–25 percent transition is slightly more correlated with the TFP-path component ($\rho = 0.07$) than the 25–50 percent transition ($\rho = 0.04$), consistent with the fact that many fast early-transition economies are also fast-converging economies, though the difference is small. The speed-column samples differ because not every country crosses both thresholds within 1950–2100: the effective sample is $N = 100$ for the 12.5% $\rightarrow$ 25% transition and $N = 80$ for the 25% $\rightarrow$ 50% transition, with countries that never reach the relevant upper threshold excluded from that column and countries already above the lower threshold in 1950 assigned the earliest available crossing year. The main message is that fiscal urgency and growth headwinds are distinct dimensions of the aging problem.

Table 13: Compression Speed, Fiscal Adjustment, and Growth Drag

Variable	Years between OADR thresholds	
	12.5% $\rightarrow$ 25%	25% $\rightarrow$ 50%
OADR 65 in 2024	0.13	0.54
Required FRA increase to maintain 2024 OADR	−0.30	−0.69
Required FRA increase to reach Japan 2024 OADR	−0.15	−0.12
Required FRA increase to reach Japan 2050 OADR	−0.13	−0.24
Aging drag on $g_{Y/N}$	0.12	0.14
TFP-path component on $g_{Y/N}$	0.07	0.04
Total drag on $g_{Y/N}$	0.09	0.07

Notes: Pearson correlations across countries, low-fertility baseline. Only $g_{Y/N}$ correlations are reported because aggregate and per-capita components coincide under the Section 4.3 decomposition. Smaller speed values indicate faster compression; negative FRA correlations mean faster compression is associated with larger required adjustments. $N = 100$ (12.5% $\rightarrow$ 25%) and $N = 80$ (25% $\rightarrow$ 50%); see text.

Thus, the same demographic transition can create fiscal urgency without a proportionate Solow growth drag, or a large growth drag without being summarized by the retirement-age statistic alone.

Figure 5 provides the visual counterpart. Within each group the relationship is strong: the correlation between demographic drag and the required increase from age 65 is -0.89 among early-aging and -0.79 among late-aging economies (and -0.87 and -0.54 , respectively, from statutory baselines)—countries with larger headwinds require larger adjustments. The pooled correlations are much weaker (-0.49 and -0.18) because the two groups occupy different regions of the drag–FRA plane: late-agers combine modest drag with large required increases ahead of their OADR ascent. The relationship is therefore systematic within groups but not mechanical across them. This is why the paper presents OADR and FRA adjustments first, then introduces the Solow model before discussing growth headwinds and their correlations with fiscal pressure.

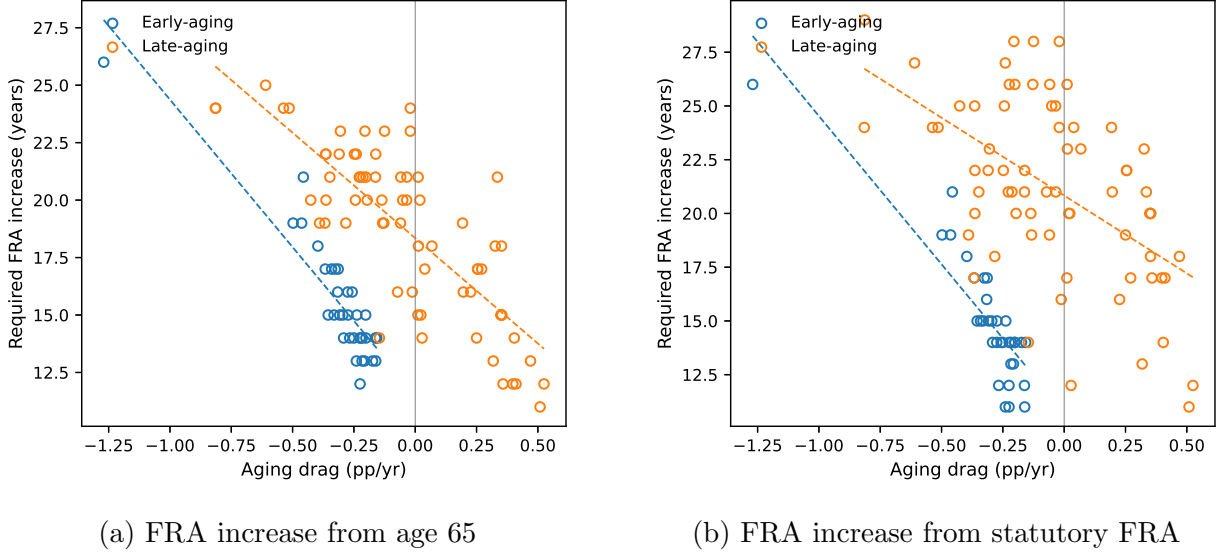


Figure 5: Required FRA Increases and Aging Drag Under Low Fertility

Notes: Aging drag is the Shapley demographic component of Section 4.3, in percentage points per year; under the fixed-2024 working-age-share counterfactual the aggregate and per-capita components coincide. Negative values are growth headwinds; positive values are demographic tailwinds. Required FRA increases maintain 2024 OADRs through 2100. Panel (a) measures from a uniform age-65 baseline under low fertility; Panel (b) measures increases from each country's current statutory FRA under low fertility. Blue circles: the early-aging economies; orange circles: the late-aging economies. Dashed lines show within-group OLS fits; the corresponding correlations are -0.89 (early) and -0.79 (late) in Panel (a) and -0.87 (early) and -0.54 (late) in Panel (b). Data: UN WPP 2024 low-fertility variant, OECD *Pensions at a Glance* 2024, PWT 11.0.

4.8 Finer Partitions of the Aging Transition

The speed measure used above spans the OADR 25–50 percent range. That range is natural for the fiscal question, since it brackets the interval over which most pension systems come under pressure, but it treats the transition as a single episode. Early-aging economies largely plateau once the OADR approaches 80 percent, whereas Korea, China, and several southern European economies continue well past 100 percent. A single interval therefore measures different things for the two groups. This subsection splits the upper transition at 75 percent and asks whether the pattern documented above—speed strongly related to the required retirement-boundary increase, weakly related to the demographic growth effect—holds segment by segment.

Of the 103 economies, 80 cross the 50 percent threshold by 2100 under low fertility, 62 cross 75 percent, and 36 cross 100 percent. The 23 that do not reach 50 percent are predominantly Sub-Saharan African economies together with Pakistan, Iraq, Uzbekistan, and Saudi Arabia; the censoring is one-tailed and reflects economies still early in the demographic transition rather than a data limitation.

Panel A of Table 14 reports each segment on its own sample. The correlation with the required FRA increase is negative and substantial on all three: -0.69 , -0.84 , and -0.52 . It is strongest on the 50–75 segment rather than on the 25–50 segment used in the baseline, so the association between speed and fiscal urgency is not an artifact of where the interval is placed.

Table 14: Compression speed, fiscal adjustment, and growth drag, by segment

OADR segment	n	Required FRA increase	Demographic drag
<i>Panel A: each segment on its own sample</i>			
25–50%	80	−0.688	+0.140
50–75%	62	−0.838	+0.318
75–100%	36	−0.521	+0.199
<i>Panel B: common subsample</i>			
25–50%	36	−0.701	+0.314
50–75%	36	−0.789	+0.405
75–100%	36	−0.521	+0.199

Note: Correlations under the low-fertility variant. Segment speeds are the number of years between first crossings of the indicated OADR thresholds, using WPP historical estimates for 1950–2023 and low-variant projections for 2024–2100. The required FRA increase is the retirement-boundary postponement from age 65 that holds the 2024 OADR fixed through 2100; the demographic drag is the Shapley demographic component of per-capita growth over 2025–2100. Panel B restricts all three segments to the 36 economies for which every crossing is defined; the 75–100 row is identical across panels by construction. Two-sided five percent thresholds are approximately ± 0.22 at $n = 80$, ± 0.25 at $n = 62$, and ± 0.33 at $n = 36$.

The correlations with the demographic growth effect remain small throughout: +0.14, +0.32, and +0.20. At these sample sizes only the 50–75 figure approaches conventional significance, and even there the FRA correlation on the same subsample is more than twice as large in absolute value.

Because the three segments are computed on different sets of economies, Panel B recomputes all three on the 36 economies for which every crossing is defined. The ordering is unchanged: FRA correlations of −0.70, −0.79, and −0.52 against demographic-drag correlations of +0.31, +0.41, and +0.20. The 75–100 row is identical across panels by construction, since the 36 economies that cross 100 percent are exactly the common subsample.

Panel B also makes a second point. On this restricted sample the 25–50 correlation with the demographic drag rises from +0.14 to +0.31. The 36 economies are those that complete the entire transition within the projection window—the fastest agers in the sample—and among them fiscal urgency and the demographic growth effect are more closely aligned than in the full cross section. This is the same compositional pattern documented in Section 4.7, where the drag–FRA relationship is strong within the early- and late-aging groups (−0.89 and −0.79) but much weaker pooled (−0.49 and −0.18). The two dimensions decouple across economies at different stages of the transition and partially recouple among those furthest along it. The orthogonality reported in this paper is therefore a statement about the full cross section of aging economies, not a claim that fiscal urgency and growth headwinds are unrelated within any particular group.

5 Robustness

This section subjects the dissociation established in Section 4 to four checks: the definition of working age, the Chinese output series, the length of the projection horizon,

and the convention used to allocate the interaction between the two channels. None overturns it.

5.1 Sensitivity to Alternative Working-Age Definitions

All baseline calculations use ages 20–64 as working age and 65+ as retirement age. To assess robustness, the online appendix replicates the analysis using ages 20–69 as working age and 70+ as retirement age. This five-year extension represents scenarios where countries successfully implement comprehensive policies extending working lives.

Table 15 presents a summary of key statistics under baseline (65+/20–64) and alternative (70+/20–69) age boundary specifications.

Table 15: Sensitivity Analysis: Alternative Age Boundaries (65+ vs. 70+ as Old Age)

	Baseline (65+ / 20–64)			Alternative (70+ / 20–69)		
Measure	Overall	Early	Late	Overall	Early	Late
<i>Panel A: Correlations</i>						
$\rho(\text{FRA inc., Drag})$	−0.49	−0.89	−0.79	−0.49	−0.92	−0.78
$\rho(\text{OADR, FRA inc.})$	−0.24	−0.20	0.40	−0.19	−0.28	0.42
<i>Panel B: Mean FRA Inc. (yrs, Low)</i>						
From baseline	17.7	15.5	18.7	16.6	15.0	17.4
Gap (Late − Early)		3.2			2.4	
<i>Panel C: Mean Drag (pp, Low)</i>						
Mean drag	0.27	0.31	0.25	0.25	0.27	0.24
Gap (Late − Early)		−0.06			−0.03	
<i>Panel D: Range (yrs, Low)</i>						
Minimum		Mali (11)			Mali (10)	
Maximum		Hong Kong (26)			Hong Kong (25)	
<i>Panel E: Selected Countries</i>						
China		24 (29)			21 (31)	
Korea		24 (24)			23 (28)	
Japan		14 (14)			14 (19)	
United States		13 (11)			14 (17)	

Notes: Baseline (65+/20–64) vs. alt. (70+/20–69) age boundaries. **Low** fertility, UN WPP 2024. $N=34$ early-aging, $N=69$ late-aging. $\rho(\text{FRA, Drag})$ uses the signed Shapley demographic drag (headwinds negative), consistent with Figure 5. Panel C reports its mean absolute value. The 70+ drag is from a re-simulation with ages 20–69 as labor input. Parentheses in Panel E: increase from statutory FRA (70-based under the alternative boundary). The within-group FRA–drag correlations are strong and significant ($p<0.001$) under both boundaries; the pooled correlation is attenuated because late-aging economies combine modest drag with large required increases. Singapore ties Hong Kong at 25 under the 70+ boundary. Medium fertility variant in the corresponding table in the online appendix, the online appendix.

Three findings emerge robustly. First, the within-group FRA–drag correlation is strong under both boundary definitions—−0.89 (early) and −0.79 (late) at the 65+ boundary, and −0.92 and −0.78 at 70+—so within each group, countries with larger demographic

headwinds require larger retirement-age adjustments. The pooled (103-country) correlation is weaker (-0.49 under both boundaries), not because the relationship fails within the late-aging group but because the two groups occupy different regions of the drag–FRA plane: late-aging economies combine still-modest near-term drag with large required increases ahead of their OADR ascent. The association is therefore systematic within groups but not mechanical across them. Second, moving to the 70+ boundary changes mean required FRA increases only modestly (17.7 to 16.6 years overall), and the late-minus-early gap narrows from 3.2 to 2.4 years; the burden of required adjustment remains larger for late-agers under either definition. Third, mean $|\text{drag}|$ falls only from 0.27 to 0.25 pp and country rankings are unchanged. Late-aging economies such as Korea (24–23 years) and China (24–21 years) face large FRA requirements under either boundary definition, and they must implement these adjustments within 14–25-year compression windows—the compressed-timeline conclusion is robust.

5.2 The Chinese GDP Series

The baseline calibration uses PWT 11.0 throughout. For one country this choice is consequential. Beginning with version 11.0, PWT reports China on its official national accounts rather than the Maddison/Wu adjusted series used through version 10.01. Because the Solow residual is computed as $\log A = \log Y - \theta \log K - (1 - \theta) \log L$, a revision to the output series passes directly into measured TFP growth: China’s g_A over 1991–2019 is 3.84% on the official series, against a frontier growth rate of $g^* = 1.11\%$. The convergence drag reported in Table 8 is therefore larger for China than for any other economy in the sample, and it is worth asking how much of that reflects the output series rather than China’s position relative to the frontier.

Table 16 recomputes the decomposition under the alternative series. Stripping 2.53 percentage points per year from the output path—the gap between the two vintages—and rescaling the capital stock proportionally lowers g_A to 2.37% and the convergence drag from -3.42 to -1.56 . Holding the capital stock at its baseline values, which bounds the case in which only measured output is revised, lowers the drag further to -0.25 .

The demographic drag is -0.81 , -0.79 , and -0.78 across the three rows. A fourteen-fold change in the convergence drag moves it by three hundredths of a percentage point. The reason is structural rather than coincidental: the demographic component is identified by the difference between the projected working-age share and the share locked at its 2024 value, and both paths are taken from the UN projections, which contain no output data at all. The output series affects the level of the growth path along which the demographic counterfactual is evaluated, but it enters baseline and counterfactual symmetrically and cancels in the difference.

The substantive conclusion of Section 4.6 for China survives in weakened form. Convergence remains the larger of the two channels, but by roughly two to one rather than four to one, and the total drag is closer to -2.4 than to -4.2 . More generally, the exercise locates the sensitivity precisely: what depends on the contested Chinese output series is the TFP-path component, and what does not is the demographic component that the paper’s central comparison rests on. Notably, when Hayashi (2026) uses the same official PWT 11.0 figures for China: his China–U.S. aggregate PPP GDP ratio for 2020 is about 1.15, matching

Table 16: China’s drag decomposition under alternative GDP series

Chinese GDP series	g_A	Demographic	TFP-path	Total
Official (PWT 11.0, baseline)	3.84%	−0.81	−3.42	−4.23
Maddison/Wu, K rescaled	2.37%	−0.79	−1.56	−2.36
Maddison/Wu, K unrevised	1.31%	−0.78	−0.25	−1.02

Note: Drag components in annualized percentage points of per-capita output growth, averaged over 2025–2100, low-fertility variant. g_A is the Solow residual over 1991–2019; the frontier is $g^* = 1.11\%$ (United States) and all three rows lie above it, so the convergence branch of equation (6) applies in each case and the comparison is not affected by the piecewise structure of the TFP path. The Maddison/Wu rows strip 2.53 percentage points per year from the output path, the difference between the two PWT vintages in China’s annualized per-capita growth over 1991–2019. The second row rescales the capital stock proportionally, on the grounds that PWT constructs capital stocks by perpetual inventory from investment measured as a share of the same output series; it is the more realistic of the two. The third row holds the capital stock at its baseline values and bounds the case in which only measured output is revised. Only China’s calibration is altered; all other countries and all demographic inputs are as in the baseline.

the value implied by the series used here rather than the 1.045 implied by the Wu (2011) reconstruction. His projected China–U.S. comparison moves accordingly, toward parity by 2050. That two independent exercises using the same demographic projections should be so sensitive to this one series underscores the point of this subsection: what depends on the contested Chinese output series is the productivity channel, and what does not is the demographic component on which the paper’s central comparison rests.

5.3 Sensitivity to the Projection Horizon

The baseline projections run to 2100, which requires demographic assumptions extending three quarters of a century beyond the last observed year. Although the age structure of the population aged 65 and over is already determined for most of that period (Section 3.7), the working-age denominator after 2060 depends on fertility that has not yet occurred. This subsection recomputes the decomposition over 2025–2060, a window in which the projected working-age population consists almost entirely of cohorts already born.

The exercise changes nothing but the averaging window. The 2024 initial conditions, the TFP convergence path, the locked-share counterfactual, and the Shapley formulas are identical; only the number of periods over which the simulated growth differentials are averaged is shortened.

Table 17 reports both horizons. The drags are uniformly smaller in absolute value over the shorter window, but the degree of shrinkage differs sharply between the two groups, and the difference is informative rather than mechanical. For the early-aging economies the demographic drag over 2025–2060 is close to its full-horizon value, and for Spain it is slightly larger (−0.44 against −0.40): their working-age decline is concentrated in the next three decades and flattens thereafter. For the late-aging middle-income economies the shorter window retains only a quarter to a half of the full-horizon drag—25 percent for Türkiye, 43 percent for Brazil, 45 percent for Chile—because most of their working-age contraction occurs after 2060. Korea is the exception within its group, retaining 89 percent, since its transition

Table 17: Growth drag over a 2060 horizon and the baseline 2100 horizon

Country	Demographic		TFP-path		Total	
	to 2060	to 2100	to 2060	to 2100	to 2060	to 2100
<i>Early-aging</i>						
Japan	−0.22	−0.29	+0.00	+0.00	−0.22	−0.29
Italy	−0.32	−0.34	+0.08	+0.11	−0.25	−0.23
Spain	−0.44	−0.40	+0.00	+0.00	−0.44	−0.40
USA	−0.04	−0.16	+0.00	+0.00	−0.04	−0.16
<i>Late-aging</i>						
South Korea	−0.72	−0.81	−0.29	−0.39	−1.01	−1.21
China	−0.43	−0.81	−2.52	−3.42	−2.95	−4.23
Thailand	−0.30	−0.43	+0.00	+0.00	−0.30	−0.43
Türkiye	−0.09	−0.36	+0.18	+0.26	+0.09	−0.11
Brazil	−0.15	−0.35	+0.00	+0.00	−0.15	−0.35
Chile	−0.23	−0.51	+0.00	+0.00	−0.23	−0.51

Note: annualized percentage points of per-capita output growth, low-fertility variant. The 2060 columns average the simulated growth differentials over 2025–2060; the 2100 columns are the baseline of Section 4. All other elements of the simulation—the 2024 initial conditions, the TFP convergence path, and the locked-share counterfactual—are unchanged.

falls almost entirely inside the window. Türkiye’s total drag changes sign across horizons, from +0.09 to −0.11, as a TFP-path tailwind that dominates before 2060 is overtaken by demographic contraction afterward.

This is the same compression documented in Section 3, seen from the growth side: what distinguishes the late-aging economies is not only the size of the eventual adjustment but how much of it lies beyond the horizon over which policy is usually evaluated. Across all 103 economies the correlation between the demographic drag to 2060 and to 2100 is 0.95, and the mean absolute difference is 0.18 percentage points.

The orthogonality between aging speed and the demographic growth effect does not depend on the length of the projection window. Over 2025–2060 the correlation between S_{25-50} and the demographic drag is −0.07, against +0.14 over the full horizon; with $n = 80$ ¹⁵ neither differs reliably from zero, and the change of sign reflects sampling variation around a null rather than a change in the underlying relationship. The correlation between S_{25-50} and the required retirement-boundary increase is unaffected by construction, since that statistic is an endpoint comparison at 2100. The finding that fiscal urgency and the demographic growth

¹⁵The correlation with S_{25-50} is computed on the 80 economies that cross the 50 percent old-age dependency threshold by 2100 under low fertility; the transition speed is undefined for the remaining 23, which are predominantly Sub-Saharan African economies together with Pakistan, Iraq, Uzbekistan, and Saudi Arabia. The horizon correlation reported in the preceding paragraph uses all 103 economies, since the demographic drag is defined for every country regardless of whether it crosses the threshold. The censoring is one-tailed and not random—the excluded economies are those still early in the demographic transition—so the speed correlations should be read as applying to the subsample that reaches the threshold within the projection window.

effect capture distinct margins is therefore not an artifact of extrapolating demographic assumptions to the end of the century.

5.4 Bounds on the Shapley Allocation

The Shapley decomposition in Section 4 assigns the interaction between the demographic and TFP channels equally to the two. That is a convention rather than a result, and it is worth reporting how much the allocation depends on it.

The two channels interact because capital accumulation responds to both. Write the four simulated growth rates as g_1 (baseline), g_2 (no aging), g_3 (no TFP normalization) and g_4 (neither). Removing the demographic channel first yields a demographic contribution of $g_1 - g_2$; removing it second yields $g_3 - g_4$. The Shapley value is the average of the two. The corresponding bounds for the TFP channel are $g_1 - g_3$ and $g_2 - g_4$. Two features of this structure limit the scope for ambiguity. First, the total drag $g_1 - g_4$ is identical under either ordering, so the decomposition affects only the split and never the sum. Second, the width of both intervals is the same quantity,

$$I = g_1 - g_2 - g_3 + g_4,$$

so a single number summarizes the ambiguity in both channels, and the Shapley value is the exact midpoint of each interval rather than an arbitrary point inside a wide range. The two channels move in opposite directions across orderings: whatever the demographic component gains, the TFP component loses.

Table 18 reports both channels with their bounds for a representative set of economies. The interaction is negligible relative to the components themselves. Across the 103 economies with complete data, the median value of $|I|$ is below 0.005 percentage points and the ninetieth percentile is 0.01, with a maximum of 0.067 points—at most 5.2 percent of the absolute total drag, and a median of well under one percent. The sign of neither component is ambiguous in any economy in the sample. China, whose TFP path moves furthest over the projection, is the largest case: reallocating the entire interaction shifts its demographic component only from -0.78 to -0.85 and its TFP component from -3.45 to -3.38 .

The equal-weighting convention is therefore not doing meaningful work: assigning the entire interaction to one channel or the other would change the reported components by at most 0.07 percentage points in any economy, would not change the sign of any component, and would leave the median economy’s rank unchanged on both margins, with a maximum shift of six positions on the demographic margin and one on the TFP margin.

6 Conclusion

This paper has measured the fiscal and growth consequences of population aging on a common basis for 103 economies, and its central finding is that the two do not coincide. The speed of transit through the critical dependency range strongly predicts the scale of the required retirement-age adjustment ($\rho = -0.69$) and is nearly unrelated to the demographic growth effect ($\rho = 0.14$). The dissociation holds on finer partitions of the transition, under a

Table 18: Shapley decomposition and the bounds from alternative orderings

Country	Demographic		TFP-path		Interaction
	Shapley	Bounds	Shapley	Bounds	
<i>Early-aging</i>					
Japan	−0.29	[−0.29, −0.29]	+0.00	[+0.00, +0.00]	0.00
Italy	−0.34	[−0.34, −0.34]	+0.11	[+0.11, +0.11]	0.00
Spain	−0.40	[−0.40, −0.40]	+0.00	[+0.00, +0.00]	0.00
USA	−0.16	[−0.16, −0.16]	+0.00	[+0.00, +0.00]	0.00
<i>Late-aging</i>					
South Korea	−0.81	[−0.82, −0.81]	−0.39	[−0.40, −0.39]	0.01
China	−0.81	[−0.85, −0.78]	−3.42	[−3.45, −3.38]	0.07
Thailand	−0.43	[−0.43, −0.43]	+0.00	[+0.00, +0.00]	0.00
Türkiye	−0.36	[−0.37, −0.36]	+0.26	[+0.25, +0.26]	0.01
Brazil	−0.35	[−0.35, −0.35]	+0.00	[+0.00, +0.00]	0.00
Chile	−0.51	[−0.51, −0.51]	+0.00	[+0.00, +0.00]	0.00

Note: annualized percentage points of per-capita output growth, 2025–2100, low-fertility variant. Bounds are the two extreme orderings: the lower bound for each channel assigns it no interaction, the upper bound assigns it all of the interaction. The Shapley value is the midpoint of each interval by construction. The interaction term $g_1 - g_2 - g_3 + g_4$ is common to both channels, so both intervals have the same width and the two channels move in opposite directions across orderings; the total drag $g_1 - g_4$ is invariant to the ordering.

shorter projection horizon, under alternative working-age boundaries, and under either allocation of the interaction between the demographic and productivity channels. It attenuates only among economies that complete the entire transition within the projection window. Projected growth drag is therefore not a sufficient statistic for fiscal urgency, and rankings built on either measure alone will misidentify which economies face the hardest adjustment.

Three measurement steps make that finding demonstrable, and each is of independent interest. Recording the time each economy takes to cross OADR thresholds shows how compressed the late-aging transitions are: Korea traverses the 25–50 percent range in a projected 14 years and China in 18, against 60 years for Germany and 80 for Sweden, and Brazil, Türkiye, Thailand, Chile, and Colombia face large increases before reaching the income and institutional levels at which earlier aging countries legislated major reforms. Expressing the implied adjustment as a demographically equivalent retirement boundary shows that reproducing 2024 OADRs in 2100 would require changes exceeding historical experience for many of them. Because that calculation abstracts from health, employment, hours, and productivity at advanced ages, the resulting ages are accounting equivalents rather than feasible targets, and their magnitude is evidence that retirement-age policy alone cannot stabilize the support ratio. Placing the same projections inside a calibrated Solow model then separates the contribution of the changing working-age share from that of productivity convergence—the latter a disciplined scenario for economies above or below the frontier growth rate, not a consequence of aging.

The dissociation between the two measures is qualified in one systematic way. Among

the 36 economies that traverse the entire transition within the projection window, fiscal urgency and the demographic growth effect move together, as they do within the early- and late-aging groups taken separately (-0.89 and -0.79 , against -0.49 pooled). The claim is therefore not that the two are unrelated, but that they do not coincide across the full cross section, because economies at different stages of the transition sit differently in the two dimensions. For early-aging economies the 25–50 percent transition lies in the past, so the projected growth drag is subsequent to it; for Korea and China the transition overlaps the projection period substantially. The orthogonality describes contemporaneous differences between the two margins rather than a temporal sequence.

One margin of adjustment is unavailable, and it is the one most often proposed. The scale documented here must be divided among later retirement, lower benefits, higher contributions, broader taxation, greater participation, and immigration. These differ in how quickly they take effect—reducing the implicit tax on continued work and raising participation act on people already in the labor force, while capital deepening and changes in the financing mix act more slowly—but each operates on cohorts already alive. Fertility does not. As Section 3.7 shows, the old-age population is already determined through 2100, and a fertility recovery raises the total dependency ratio for two to three decades before it lowers it. Family policy and fiscal adjustment address different horizons; they are complements rather than substitutes.

The policy implication is not that all countries should respond with the same instrument. Pension institutions, labor markets, health conditions, informality, and political constraints differ widely. The implication is that late adjustment is costly. Automatic adjustment rules—Sweden’s notional accounts, Germany’s sustainability factor, Japan’s 2004 macroeconomic slide—spread the burden across cohorts precisely because small annual changes compound over decades, and that compounding requires calendar time the late-aging economies do not have. Imrohoroglu (2026) quantifies this for the United States and Japan and extends a simplified version of the calculation across countries. Economies that wait until their dependency ratios approach Japan’s current level will have less room for gradual indexation and will need sharper changes in benefits, contributions, or retirement ages.

Several limitations remain. The paper does not solve a full overlapping-generations model for each country, does not model behavioral responses to retirement-age changes, and abstracts from distributional consequences within countries. It treats the Solow model as an accounting device rather than as a theory of aging and growth, and the demographic component it measures is a lower bound on the total effect of aging, since any effect operating through productivity is absorbed into the measured TFP residual. These limitations are the price of comparability across 103 economies. The central conclusion is unaffected: many late-aging economies face large fiscal adjustments with unusually little calendar time in which to distribute them, and the relevant policy question is not whether they must adjust but how early they adopt mechanisms that spread the adjustment across cohorts.

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Appendix roadmap. The appendix collects sample details, calibration information, and robustness checks that support the main text. Appendix A lists the countries in the 103-economy sample and shows the early- and late-aging classification used throughout the paper. Appendix B compares the UN WPP fertility variants with alternative fertility projections and explains why the low-fertility variant is used as the baseline, while the medium-fertility variant is reported as an optimistic benchmark. Appendix C reports the calibrated Solow parameters for all countries and describes the construction of depreciation rates, capital shares, investment rates, and historical TFP growth rates from Penn World Table data. Appendix D examines the implications of using working-age population rather than employment as the labor input, and documents the robustness of the growth-accounting exercise to this choice. The medium-fertility counterparts to the main low-fertility results—including the medium-fertility OADR, retirement-age, growth-drag, and age-boundary sensitivity tables—are reported in a supplementary online appendix.

A Country Sample and Early/Late-Aging Classification

The sample comprises 103 economies spanning all major world regions and levels of economic development. Countries are classified using their 2024 old-age dependency ratio (OADR), defined in Section 3 as the population aged 65 and above relative to the population aged 20–64: countries with a 2024 OADR of 30 percent or higher are classified as *early-aging* (34 countries, Table 19), and countries with a 2024 OADR below 30 percent are classified as *late-aging* (69 countries, Table 20). As discussed in Section 3, this 30 percent cutoff produces a level-based taxonomy rather than a direct measure of transition speed, and the paper’s main findings are robust to alternative cutoffs of 28 and 32 percent. Within each table, countries are listed in the same order as Tables 1 and 2 (2024 OADR, descending).

Table 19: Early-Aging Economies (34 Countries)

Japan	Germany	Denmark	Austria	Norway
Finland	Serbia	Hong Kong	Romania	United States
Portugal	Latvia	Czechia	United Kingdom	Ukraine
Italy	Bulgaria	Belgium	Poland	Slovakia
Greece	Slovenia	Hungary	Lithuania	Australia
Croatia	Estonia	Spain	Switzerland	New Zealand
France	Sweden	Netherlands	Canada	

Notes: Ordered by 2024 OADR (descending), reading down each column before proceeding to the next, consistent with Table 1

Table 20: Late-Aging Economies (69 Countries)

South Korea	Brazil	Iran	Egypt	Angola
Belarus	Türkiye	Malaysia	Mongolia	Sudan
Russia	Panama	Indonesia	Guatemala	Niger
Uruguay	Tunisia	Myanmar	Pakistan	Mozambique
Ireland	Kazakhstan	India	Rwanda	Mali
Iceland	Peru	Algeria	Jordan	Cameroon
Israel	Colombia	Nepal	Zimbabwe	Kenya
Thailand	Viet Nam	Bangladesh	Honduras	Burkina Faso
China	Ecuador	Paraguay	Senegal	Malawi
Chile	Morocco	South Africa	Ghana	Côte d’Ivoire
Argentina	Mexico	Cambodia	Tanzania	Uganda
Sri Lanka	El Salvador	Uzbekistan	Ethiopia	Saudi Arabia
Singapore	Dominican Republic	Bolivia	Iraq	Zambia
Costa Rica	Azerbaijan	Philippines	Nigeria	

Notes: Ordered by 2024 OADR (descending), reading down each column before proceeding to the next, consistent with Table 2

B Fertility Projection Comparison

The choice of fertility scenario has large consequences for projected old-age dependency ratios. Because fertility determines the size of the working-age cohorts entering the labor market from 2040 onward, a difference of even 0.3–0.5 in the assumed long-run total fertility rate (TFR) compounds into dramatically different OADR levels by 2080–2100. This appendix compares the four scenarios used to bound uncertainty in the main analysis: the UN World Population Prospects (WPP 2024) medium and low variants, and the Institute for Health Metrics and Evaluation (IHME) Global Burden of Disease reference-scenario mean and lower-bound projections.

The WPP medium variant assumes that below-replacement countries gradually recover fertility toward intermediate levels—typically 1.4–1.7 children per woman for East Asia and 1.6–1.9 for Southern Europe—by mid-century. The WPP low variant, by contrast, holds long-run fertility roughly half a child below the medium path, which the UN defines probabilistically as the 20th percentile of its demographic model. The IHME projections are methodologically independent: they use a socio-demographic regression framework rather than the UN’s cohort-component method, and they incorporate education, female labor-force participation, and access to contraception as explicit drivers of fertility change. The IHME lower bound represents the pessimistic tail of the IHME uncertainty distribution, corresponding broadly to scenarios where female empowerment and economic development accelerate fertility decline beyond what the reference model projects.

Figure 6 plots projected TFRs for five illustrative economies: China, South Korea, Chile, Spain, and India. These span a wide range of current fertility levels and cover the key analytical cases discussed below. The horizontal dashed line at 2.1 marks replacement-level fertility.

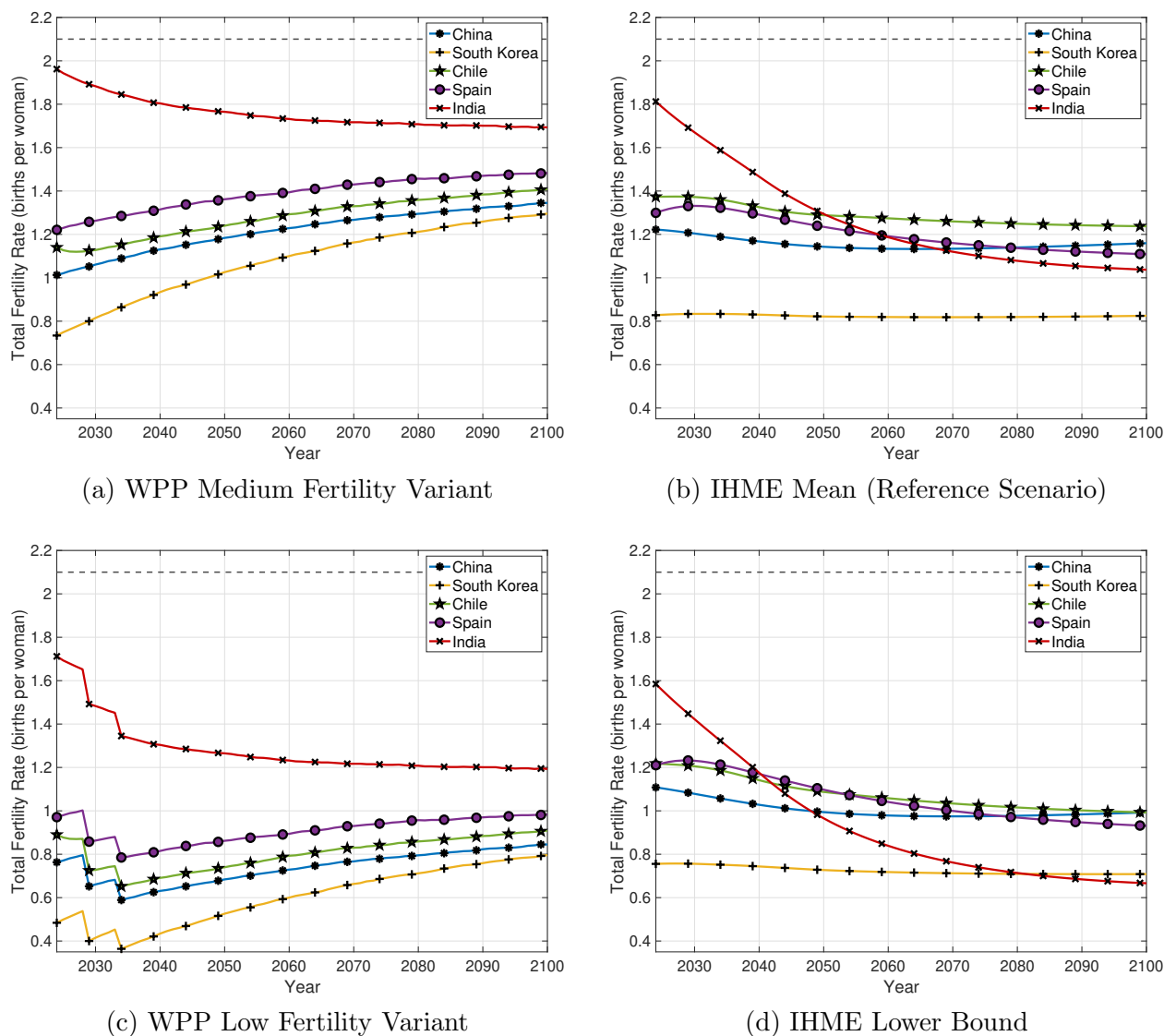


Figure 6: Total Fertility Rate Projections for Selected Countries (2024–2100). Panel (a) shows the UN World Population Prospects medium fertility variant. Panel (b) shows the IHME reference-scenario mean projection. Panel (c) shows the WPP low fertility variant. Panel (d) shows the IHME lower-bound projection. The horizontal dashed line at 2.1 indicates replacement-level fertility.

Several patterns stand out.

Korea: the pessimistic case. South Korea recorded a TFR of approximately 0.72 in 2023—the lowest ever measured for any large economy. The WPP medium variant embeds a substantial recovery toward 1.4–1.5 by 2050. The IHME reference scenario is considerably more pessimistic, remaining closer to 0.9–1.0 for Korea through mid-century, consistent with observed trends and the social dynamics driving delayed marriage and childlessness in East Asian societies. The divergence between WPP medium and IHME reference is largest for Korea, and it is precisely this divergence that accounts for the largest differences in projected

OADRs shown in the main tables: under WPP medium Korea’s OADR reaches 105.9% by 2100, while under WPP low it reaches 196.2%. The IHME reference sits closer to WPP low, suggesting that WPP low—the main paper’s baseline—is the better “central” case for these economies rather than an extreme pessimistic scenario.

China: structural break from the one-child era. China’s TFR fell from around 1.7 in the early 2010s to an estimated 1.0–1.1 by 2022–2023, despite the reversal of the one-child policy in 2016 and the pronatalist incentives introduced since 2021. WPP medium assumes a gradual recovery to approximately 1.4 by 2050. The IHME reference is notably lower, projecting little rebound and sustained fertility below 1.2 through 2050. Because China’s working-age population is already declining, the difference between these paths matters acutely: moving from WPP medium to WPP low raises China’s 2100 OADR from 106% to 207%—a doubling of the old-age burden that depends almost entirely on the fertility assumptions made for the 2025–2050 birth cohorts.

India: intermediate trajectory. India currently has a TFR around 2.0, close to but still slightly above replacement. All four scenarios agree on continued gradual decline, with WPP medium and IHME reference projecting convergence toward 1.6–1.8 by mid-century. The divergence between scenarios is moderate compared to East Asia. India’s aging trajectory therefore lies between the extremes: a meaningful long-run increase in the OADR, but at a pace closer to Western Europe than to Korea or China.

Chile and Spain: mid-range low fertility. Chile and Spain both have TFRs around 1.5–1.6, below replacement but substantially higher than East Asia. The WPP medium and low variants bracket a moderate range, with the IHME reference generally sitting between them for these economies. The consequence is that their projected OADR outcomes are less sensitive to scenario choice than Korea or China, though both face substantial aging under any scenario.

High-fertility economies (not shown in figure). For Sub-Saharan African economies such as Nigeria, Niger, Mali, and Uganda, TFRs of 4.5–7.0 remain far above replacement across all four scenarios through mid-century. All scenarios agree on a downward trajectory, but differ on pace. Even under the WPP low variant, Sub-Saharan Africa retains TFRs well above replacement through mid-century, which is why these economies show demographic *tailwinds* in the Solow model: their working-age populations continue expanding rapidly regardless of which scenario is used.

United States and Western Europe (not shown in figure). The United States, France, and Sweden have TFRs of 1.6–1.8—below replacement but substantially higher than East Asia. For these economies, the WPP medium and low variants are close, and the IHME reference scenario sits between them. The consequence is that US and Western European projected OADRs are relatively insensitive to the choice of scenario: the gap between WPP medium and WPP low OADRs in 2100 is on the order of 15–25 percentage points for these economies, compared with 80–100 percentage points for Korea and China.

Why WPP low is the baseline. The comparison supports the main text’s choice to use WPP low fertility as the primary baseline for three reasons. First, for the economies with the most severe projected aging—Korea, China, Japan—the IHME reference scenario is closer to WPP low than to WPP medium, meaning that WPP medium embeds a more optimistic fertility rebound than the independent IHME methodology endorses. Second, realised fertility in 2020–2023 has surprised on the downside relative to WPP 2019 medium projections in virtually all low-fertility countries: WPP 2024 has already revised the medium path downward for Korea, China, and Japan compared with earlier editions. Third, because the fiscal and growth-drag results are most consequential for the scenarios that place the heaviest burden on pension systems, presenting the WPP low results as the central case and the WPP medium results as the optimistic alternative is the more appropriate framing for a policy audience.

This rationale applies most forcefully to the ultra-low-fertility economies (Korea, China, Japan) where the two scenarios diverge most dramatically. For high-fertility Sub-Saharan African and South Asian economies, where both WPP scenarios project fertility well above replacement through mid-century, the low-fertility variant is better interpreted as a stress scenario applied uniformly for cross-country comparability rather than as a central demographic forecast. The medium-fertility tables in the online appendix provide the counterpart results, and for high-fertility economies the two scenarios yield broadly similar conclusions about demographic drag direction and the relative ordering of countries.

The comparison shows why the WPP medium variant is best interpreted as an optimistic benchmark rather than as the only central case. WPP medium assumes a gradual rebound in fertility, while the IHME reference scenario is closer to WPP low for several economies where observed fertility has recently surprised on the downside. The discrepancy is especially relevant for China and Korea, where projected OADRs are highly sensitive to the size of cohorts born over the next several decades. The figures therefore support the main text’s choice to use WPP low fertility as the baseline and to place WPP medium results in the online appendix.

C Calibrated Parameters

Table 22 reports the four model parameters calibrated from Penn World Table 11.0 data over 1991–2019 for all 103 economies in the sample. The full calibrated parameters for all 103 economies appear as Table 22 in the appendix. This appendix describes the calibration procedure, discusses cross-country heterogeneity in each parameter, and flags notable outliers.

Depreciation rate $\hat{\delta}$. The depreciation rate is computed as the average of the PWT variable `delta` (economic depreciation of the capital stock) over 1991–2019. Across the 103 economies, $\hat{\delta}$ ranges from 2.5% (Ukraine, Latvia) to 7.9% (Myanmar), with a cross-country mean of 4.3%. Advanced economies cluster in the 3.5–4.5% range, consistent with the standard macroeconomic calibration of approximately 4–5% per year. Several transition economies (Ukraine, Latvia) have unusually low estimated depreciation, possibly reflecting underreported retirement of Soviet-era capital stock during the 1990s. High values

for Myanmar (7.9%), Pakistan (7.6%), and Romania (7.3%) reflect more rapid turnover of shorter-lived capital assets in manufacturing-intensive or rapidly industrializing economies.

Capital share $\hat{\theta}$. The capital share is computed as $\hat{\theta} = 1 - \overline{\text{labsh}}$, where $\overline{\text{labsh}}$ is the PWT average labor compensation share of GDP over 1991–2019. To prevent implausibly high capital shares driven by measurement error or resource-sector income, $\hat{\theta}$ is winsorized to the interval $[0.25, 0.65]$. The upper bound of 0.65 binds for 31 economies, predominantly resource-dependent countries (Algeria, Angola, Iraq, Saudi Arabia) and several low-income Sub-Saharan African economies where labor income is difficult to measure separately from mixed agricultural income. The lower bound of 0.25 does not bind for any economy in the sample. Conditional on not being winsorized, the capital share ranges from 0.259 (Rwanda) to 0.647 (Mexico), with a mean of approximately 0.47. Canada (0.336), Portugal (0.373), and the United States (0.394) have relatively low capital shares, consistent with their high labor compensation ratios. Korea (0.459) and China (0.422) are in the middle of the distribution.

Investment (saving) rate $\hat{s}$. The saving rate is the average of the PWT investment-to-GDP ratio `csch_i` over 1991–2019. Across the 103 economies, $\hat{s}$ ranges from 6.6% (Zimbabwe) to 40.0% (Singapore), with a mean of 22.1%. The East Asian high savers stand out: Singapore (40.0%), China (37.5%), and South Korea (37.3%) all have saving rates roughly double the sample mean, consistent with the well-documented East Asian saving puzzle. At the low end, Zimbabwe (6.6%), Côte d’Ivoire (9.6%), and Egypt (10.5%) reflect periods of severe economic and political instability that suppressed domestic investment over the calibration window. The saving rate matters for the Solow projection because it determines how quickly the capital stock adjusts to shocks in working-age population; economies with high $\hat{s}$ accumulate replacement capital faster when labor supply contracts.

TFP growth rate $\hat{g}_A$. The TFP growth rate is the centrepiece of the calibration. It is computed as the average annual log-difference of the Hicks-neutral Solow residual $A_t = Y_t / (K_t^\theta N_{w,t}^{1-\theta})$ over 1991–2019, where $N_{w,t}$ is WPP 2024 working-age population (ages 20–64) rather than PWT employment (see Appendix [D](#)).

The resulting $\hat{g}_A$ values span a wide range: from -6.35% per year (Azerbaijan) to $+4.24\%$ per year (Iraq), with a cross-country mean of 0.81% . The negative values deserve particular attention.^{[16](#)} Azerbaijan’s $\hat{g}_A = -6.35\%$ reflects the severe disruption of the 1991–1995 post-Soviet collapse and subsequent dependence on oil revenues whose GDP contribution is highly volatile; similarly, Saudi Arabia’s -2.17% and Uzbekistan’s -1.37% reflect resource-sector volatility and transition costs. Bulgaria (-1.87%) experienced deep output contraction in the late 1990s following the 1996–97 banking crisis. These economies have

¹⁶Because $\hat{g}_A$ is a Solow residual, it turns negative whenever measured inputs grow faster than output, not only when technology regresses. In Saudi Arabia, the working-age population roughly tripled over 1991–2019 and oil revenue financed steady capital accumulation, while real output was constrained by OPEC quantity restraint rather than productivity, so the residual declines mechanically. Azerbaijan combines the 1991–95 post-Soviet output collapse with an oil boom in which extraction capital and labor grew rapidly against volatile constant-price oil output; Uzbekistan and Bulgaria reflect transition disruption, the latter culminating in the 1996–97 banking crisis. The zero-growth floor of Section [4.3](#) prevents these episode-driven residuals from being extrapolated over a 75-year horizon.

$\hat{g}_A < 0$; under the model’s convergence rule, their baseline TFP growth converges upward to zero by 2045, while the no-transition counterfactual would keep TFP growth at the (negative) historical rate. The baseline therefore *improves* relative to the counterfactual, generating a *positive* TFP-path component (a tailwind) for these economies, as reflected in Table 12 for Azerbaijan, Myanmar, and similar cases. The large positive TFP entry for Azerbaijan in that table (TFP $Y/N = +7.513$) reflects the severity of its historically negative TFP growth rate (-6.35%) and the large gain from convergence to zero.

Table 21 lists all $N = 14$ economies in the 103-country sample with $\hat{g}_A < 0$, together with their calibrated historical TFP growth rates and the resulting Shapley TFP-path tailwinds. Under the model’s convergence rule, each of these economies is assumed to converge linearly from its historical rate up to zero TFP growth by 2045 and to remain at zero thereafter, so the magnitude of the tailwind is increasing in the severity of historical TFP decline.

Table 21: Economies with Negative Historical TFP Growth ($\hat{g}_A < 0$)

Country	Group	$\hat{g}_A$ (%)	TFP Y/N	Country	Group	$\hat{g}_A$ (%)	TFP Y/N
Azerbaijan	Late	-6.35	7.513	Mexico	Late	-0.27	0.373
Saudi Arabia	Late	-2.17	3.163	Türkiye	Late	-0.18	0.255
Bulgaria	Early	-1.87	2.314	Kenya	Late	-0.13	0.178
Uzbekistan	Late	-1.37	1.647	Honduras	Late	-0.09	0.115
Myanmar	Late	-0.95	1.499	Panama	Late	-0.08	0.109
Ukraine	Early	-0.69	0.653	Italy	Early	-0.09	0.108
Viet Nam	Late	-0.31	0.464	Algeria	Late	-0.06	0.094

Notes: $\hat{g}_A$ = calibrated 1991–2019 TFP growth (Solow residual).
TFP Y/N = Shapley TFP-path component, low fertility, from
Tables 11–12. $N = 14$; sorted by TFP-path component (de-
scending).

At the upper end, Iraq (4.24%) and China (3.84%) record the highest TFP growth rates, both driven by rapid capital-efficient output expansion over the period. Mali (2.58%), Nigeria (2.52%), and Mongolia (2.45%) follow, all reflecting either commodity-driven productivity gains or strong catch-up from a low base. The frontier economy is the United States at $g^* = 1.11\%$ per year; economies above this threshold account for 36 of the 103 countries and face a TFP-path component in the Solow projection as their TFP growth converges to g^* by 2045. Japan’s $\hat{g}_A = 0.33\%$ sits well below the frontier, so it carries no negative TFP-path component and its total growth headwind comes entirely from the demographic channel. South Korea’s $\hat{g}_A = 1.42\%$ exceeds the frontier by 0.31 percentage points, generating a TFP-path component of -0.39 pp/yr that is roughly half its demographic drag (-0.815 pp/yr), making Korea an economy where both channels impose large but unequal burdens.

Table 22: Calibrated Parameters by Country (All 103 Economies)

Country	$\hat{\delta}$	$\hat{\theta}$	$\hat{s}$	$\hat{g}_A$ (%)	Country	$\hat{\delta}$	$\hat{\theta}$	$\hat{s}$	$\hat{g}_A$ (%)
Algeria	0.040	0.650	0.298	-0.0623	Lithuania	0.033	0.484	0.171	1.3793
Angola	0.042	0.650	0.369	0.3520	Malawi	0.058	0.650	0.161	2.1080
Argentina	0.034	0.558	0.161	0.4793	Malaysia	0.052	0.650	0.300	0.3293
Australia	0.030	0.406	0.265	1.1293	Mali	0.066	0.650	0.144	2.5799
Austria	0.039	0.387	0.297	0.6781	Mexico	0.035	0.647	0.193	-0.2702
Azerbaijan	0.061	0.645	0.159	-6.3467	Mongolia	0.042	0.614	0.263	2.4540
Bangladesh	0.045	0.650	0.210	0.2675	Morocco	0.047	0.491	0.282	0.6513
Belarus	0.039	0.443	0.187	1.2368	Mozambique	0.047	0.497	0.254	0.9603
Belgium	0.041	0.373	0.300	0.6445	Myanmar	0.079	0.650	0.162	-0.9483
Bolivia	0.056	0.488	0.139	0.8690	Nepal	0.035	0.650	0.213	0.0306
Brazil	0.047	0.450	0.193	0.0737	Netherlands	0.039	0.394	0.228	1.1066
Bulgaria	0.060	0.518	0.145	-1.8666	New Zealand	0.032	0.451	0.221	1.0019
Burkina Faso	0.044	0.497	0.151	0.8447	Niger	0.032	0.533	0.168	1.6026
Cambodia	0.037	0.650	0.213	0.0885	Nigeria	0.030	0.650	0.205	2.5189
Cameroon	0.049	0.365	0.130	0.3561	Norway	0.042	0.494	0.232	0.5010
Canada	0.035	0.336	0.246	0.7823	Pakistan	0.076	0.650	0.123	1.0428
Chile	0.034	0.548	0.258	0.7260	Panama	0.046	0.600	0.251	-0.0774
China	0.054	0.422	0.375	3.8377	Paraguay	0.036	0.538	0.208	0.6085
Colombia	0.034	0.521	0.200	0.5857	Peru	0.040	0.543	0.217	0.8499
Costa Rica	0.052	0.435	0.181	0.6149	Philippines	0.045	0.571	0.181	0.7245
Côte d'Ivoire	0.043	0.577	0.096	0.9654	Poland	0.046	0.398	0.179	2.1674
Croatia	0.042	0.364	0.213	1.4282	Portugal	0.029	0.373	0.273	0.3983
Czechia	0.041	0.487	0.259	1.8200	Romania	0.073	0.513	0.201	1.2982
Denmark	0.040	0.362	0.255	0.8912	Russia	0.033	0.486	0.189	0.9719
Dominican Rep.	0.039	0.484	0.225	1.8001	Rwanda	0.047	0.259	0.113	2.1510
Ecuador	0.038	0.492	0.214	1.1332	Saudi Arabia	0.053	0.650	0.294	-2.1723
Egypt	0.059	0.625	0.105	0.7009	Senegal	0.043	0.512	0.160	0.0321
El Salvador	0.049	0.518	0.145	0.0933	Serbia	0.033	0.376	0.163	0.8435
Estonia	0.039	0.410	0.250	1.7374	Singapore	0.049	0.556	0.400	1.1276
Ethiopia	0.039	0.650	0.154	0.9359	Slovakia	0.043	0.494	0.238	1.9629
Finland	0.037	0.413	0.276	1.1284	Slovenia	0.037	0.339	0.278	1.7567
France	0.033	0.358	0.238	0.8065	South Africa	0.047	0.441	0.160	0.4832
Germany	0.035	0.358	0.231	0.8435	South Korea	0.047	0.459	0.373	1.4209
Ghana	0.055	0.650	0.277	1.7419	Spain	0.035	0.381	0.278	0.4935
Greece	0.029	0.465	0.229	0.2815	Sri Lanka	0.065	0.576	0.231	0.8687
Guatemala	0.038	0.542	0.151	0.3665	Sudan	0.039	0.304	0.138	1.3657
Honduras	0.056	0.421	0.223	-0.0930	Sweden	0.039	0.391	0.259	1.3310
Hong Kong	0.030	0.501	0.271	0.9942	Switzerland	0.048	0.342	0.317	0.4402
Hungary	0.036	0.400	0.221	1.5269	Türkiye	0.051	0.577	0.247	-0.1834
Iceland	0.033	0.356	0.284	1.3735	Tanzania	0.041	0.534	0.245	0.8316
India	0.047	0.442	0.250	2.0272	Thailand	0.062	0.541	0.273	0.9318
Indonesia	0.040	0.492	0.253	0.6525	Tunisia	0.047	0.485	0.185	1.3992
Iran	0.040	0.607	0.263	0.0328	USA	0.039	0.394	0.239	1.1061
Iraq	0.045	0.650	0.197	4.2366	Uganda	0.047	0.650	0.170	0.2692
Ireland	0.042	0.518	0.288	1.9294	Ukraine	0.025	0.449	0.142	-0.6916
Israel	0.042	0.467	0.308	0.9067	United Kingdom	0.037	0.406	0.213	0.9098
Italy	0.036	0.464	0.260	-0.0938	Uruguay	0.031	0.490	0.196	1.4979
Japan	0.039	0.434	0.293	0.3280	Uzbekistan	0.041	0.575	0.132	-1.3653
Jordan	0.035	0.520	0.281	0.9055	Viet Nam	0.051	0.650	0.229	-0.3079
Kazakhstan	0.043	0.536	0.178	2.1843	Zambia	0.041	0.578	0.239	1.7721
Kenya	0.049	0.504	0.132	-0.1343	Zimbabwe	0.043	0.467	0.066	0.7945
Latvia	0.025	0.456	0.223	1.6459					

Notes: $\hat{\delta}$ = average depreciation rate; $\hat{\theta}$ = capital share (1 - labor share); $\hat{s}$ = average investment rate; $\hat{g}_A$ = compound annual TFP growth rate. All computed as 1991–2019 averages from Penn World Table 11.0.

Alternative Calibration: Recovering the Implied Real Saving Rate

To perfectly align the valuation units of the investment flow with the Penn World Table constant-price capital stock ($rnna$) and constant-price real GDP ($rgdpna$), we can

back out the implied real saving rate directly from the capital accumulation identity rather than using current-price shares.

Based on the discrete-time capital law of motion, the real investment flow required to generate the observed change in the empirical capital stock is the difference between next year’s capital and the undepreciated portion of this year’s capital. Let $K_{i,t}$ be the constant-price capital stock, $Y_{i,t}$ be constant-price real GDP, and $\delta_{i,t}$ be the depreciation rate for country i in year t . The implied real saving rate $s_{i,t}$ solves the identity:

$$s_{i,t} Y_{i,t} = K_{i,t+1} - (1 - \delta_{i,t}) K_{i,t} \quad (8)$$

Dividing by real output isolates the implied real saving rate for that specific year:

$$s_{i,t} = \frac{K_{i,t+1} - (1 - \delta_{i,t}) K_{i,t}}{Y_{i,t}} \quad (9)$$

The calibrated, country-specific constant-price saving rate $\hat{s}_i$ applied uniformly over the projection period is then the time-series average of this implied rate over the 1991–2019 horizon:

$$\hat{s}_i = \frac{1}{2019 - 1991 + 1} \sum_{t=1991}^{2019} \left(\frac{rnn_{i,t+1} - (1 - \delta_{i,t}) rnn_{i,t}}{rgdp_{i,t}} \right) \quad (10)$$

Using this derived $\hat{s}_i$ guarantees that the forward-simulated capital path remains strictly valuation-consistent with the empirical 2023 initial conditions.

As a robustness check, we compute $\hat{s}_i$ for four focal economies and compare it to the baseline current-price investment share $\bar{s}_i = \overline{csh_i}$ used throughout the paper. Table 23 reports the two saving rates and the resulting Shapley demographic drag on per-capita GDP growth under each calibration.

Table 23: Baseline vs. Implied Real Saving Rate: Four Focal Economies

Country	$\bar{s}_i$	$\hat{s}_i$	Drag $g_{Y/N}$, base	Drag $g_{Y/N}$, alt	Diff (pp)
USA	0.2394	0.2136	−0.1610	−0.1607	0.0003
Japan	0.2934	0.2828	−0.2917	−0.2912	0.0005
China	0.3746	0.5863	−0.8128	−0.8159	−0.0031
South Korea	0.3735	0.4625	−0.8147	−0.8195	−0.0047

Notes: $\bar{s}_i$ = mean current-price investment share (csh_i) over 1991–2019, used as the baseline throughout the paper. $\hat{s}_i$ = mean implied real saving rate recovered from the capital accumulation identity (equations above) using rnn and $rgdpna$. Drag $g_{Y/N}$ = Shapley demographic drag on per-capita GDP growth, low fertility, 2024–2100. Diff = alternative minus baseline drag.

For the USA and Japan the two measures agree closely (within 1–2 percentage points), and the implied drag difference is negligible (≤ 0.001 pp). For China and South Korea the implied real saving rate is substantially higher—58.6% and 46.3% versus 37.5% and 37.4%—reflecting that the PWT constant-price capital series embeds larger real investment volumes

than the current-price investment share suggests. The discrepancy arises from the index-number construction of constant-price series in the Penn World Tables: for fast-growing economies, the deflation procedure can embed different real investment volumes than the nominal share implies. Even so, the effect on the demographic drag estimate is negligible in both cases (≤ 0.005 pp over the 76-year projection horizon), confirming that the main results are insensitive to this calibration choice. We therefore retain the standard current-price investment share throughout.

D Labor-Input Choice: WPP Working Age vs. PWT Employment

This paper calibrates TFP growth using WPP 2024 working-age population (ages 20–64) as the labor input, consistently with the projection period. An alternative standard in the literature [Fernández-Villaverde, Ventura, and Yao \(2025\)](#) uses PWT 11.0 employment ($emp_{i,t}$) as the labor input in their growth-accounting framework; the production-function structure adopted here follows their insight that working-age population is the appropriate denominator for GDP-per-worker comparisons, but departs from their calibration by using WPP working-age population throughout for internal consistency with the demographic projection. The two calibrations diverge where employment rates trended over 1991–2019. In Japan and Korea, employment-to-working-age ratios rose, so the WPP-consistent TFP rates exceed the employment-based ones (0.33% versus 0.06% for Japan, 1.42% versus 1.23% for Korea); in China, the working-age population grew faster than employment, so the ordering reverses (3.84% versus 4.23%). Table [24](#) reports both calibrations for six economies, with the alternative fully recalibrated: TFP growth and the 2023 TFP level use employment as the labor input, the frontier rate becomes $g^* = 1.07\%$ (versus 1.11%), and projections hold each country’s 2023 employment-to-working-age ratio constant along the WPP low-fertility path, leaving $\hat{\theta}$, $\hat{\delta}$, $\hat{s}$, and K_{2024} unchanged. Three results stand out. First, for the United States, Japan, and Russia the TFP-path component is zero under both calibrations—each economy’s TFP growth lies below the frontier on either basis—so total drag is purely demographic and identical to the second decimal (−0.16, −0.29, and −0.15 pp/yr). Second, China’s convergence penalty is large under either calibration and somewhat larger on the employment basis (−3.95 versus −3.42 pp/yr; total −4.77 versus −4.23), whereas Korea’s is about twice as large on the WPP basis (−0.39 versus −0.19 pp/yr). Third, Türkiye’s negative-TFP convergence tailwind shrinks from +0.26 to +0.05 pp/yr under the employment basis. The demographic component is essentially invariant to the labor-input choice (differences are at most 0.01 pp/yr across the six economies), and the qualitative ranking of countries by severity of total drag is preserved across both calibrations.

Table 24: TFP-path component: WPP Working-Age (Baseline) vs. PWT Employment Calibration (Low Fertility, Selected Economies)

Country	TFP growth (%)		TFP-path component (pp/yr)		Total drag (pp/yr)	
	WPP N_w	PWT emp	WPP N_w	PWT emp	WPP N_w	PWT emp
United States	1.11	1.07	+0.00	+0.00	−0.16	−0.16
Japan	0.33	0.06	+0.00	+0.00	−0.29	−0.29
China	3.84	4.23	−3.42	−3.95	−4.23	−4.77
Russia	0.97	1.05	+0.00	+0.00	−0.15	−0.15
South Korea	1.42	1.23	−0.39	−0.19	−1.21	−1.00
Türkiye	−0.18	−0.04	+0.26	+0.05	−0.11	−0.31

Notes: WPP N_w = baseline (this paper): labor input is the WPP working-age population in calibration (1991–2019) and projection. PWT emp = alternative: TFP growth and the 2023 TFP level are recalibrated with PWT 11.0 employment; projections hold each country’s 2023 employment-to-working-age ratio constant along the WPP low-fertility path. $\hat{\theta}$, $\hat{\delta}$, $\hat{s}$, and K_{2024} are identical across calibrations. Frontier rates: $g^* = 1.11\%$ (WPP), 1.07% (PWT emp). TFP-path component and total drag are Shapley components on $g_{Y/N}$, pp/yr, low fertility.