Terra Incognita:
The Economics of a Shrinking World

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August 10, 2026

Abstract

As of 2026, humanity is likely below replacement fertility. That has never happened before, not in wars or pandemics. But the real surprise is that the fall has been concentrated in low- and middle-income countries and among poorer and less educated women. We fit a single-factor model to 236 countries since 1950: the common component peaked in 1978, and what drives fertility down today are country-specific trends, 219 of them negative and not one leveling off. None of the commonly cited mechanisms can account for this pattern, so we offer a conjecture: modernity itself, which makes a third child expensive and childlessness cheap. Children come in integers, so it takes very little to move a cohort's fertility rate from 1.8 to 1.3. And nothing in an economy pushes fertility back to 2.1. We close with the main economic consequences, in particular slow growth.

Keywords: fertility decline; demographic transition; population aging; economic growth; labor force; population projections

JEL Classification: J11; J13; O40; E24; O11

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1 Introduction

As of 2026, humanity is likely to be below replacement level: we are having fewer births than we need to keep population constant in the long run. As far as we can tell, this has never happened before in our history as a species, not even during wars or pandemics.[1]

This astonishing fact does not mean that population has stopped growing. Because of momentum effects (the large cohorts of women born two or three decades ago are having their children now, and their own parents have not died yet), world population will keep growing for another 30 years or so. But unless trends change, world population will peak at roughly 9 billion around 2056 and then start falling, first slowly, then fast.[2] China, the most populous country until India overtook it, already records 3.3 million more deaths than births a year.

Falling below replacement follows from a fast and accelerating drop in fertility worldwide. Demographers and economists have long expected fertility to fall, but its decline over the last decade has been unusually steep, above all in countries where no one expected such a fast decline. Mexico's total fertility rate (TFR) in 2025, 1.51, for instance, is likely to be below that of non-Hispanic whites in the U.S., 1.57, despite a GDP per capita at purchasing power parity (PPP) of only around 28% of the U.S. level.[3] Even more striking is Tunisia, whose TFR in 2024 stood at 1.45 with a GDP per capita at PPP of 18% of the U.S. level.

Mexico and Tunisia are not anomalies. In 2025, Thailand was at 0.87, Colombia at 1.01, Iran at 1.35, and Brazil at 1.52, all at a fraction of U.S. per capita income. We stop at four only to spare the reader a long list. Never before have we seen middle-income countries fall below rich countries in fertility.[4] Within the OECD, the cross-country correlation between the total fertility rate and per capita GDP, historically negative, switched to positive during the 1980s.

This inversion of the historical relationship between income and fertility across countries also seems to be happening within countries. The negative relationship between household income

[1] Supplementary Material A defines replacement rate carefully, as well as other basic demographic concepts.

[2] Unless otherwise stated, we will use the most recent data from the official statistical office of each country. The United Nations' World Population Prospects (UN WPP) 2024 (United Nations, 2024) "Medium Variant" postpones the start of the world population fall to 2084. Supplemental Material B explains why our estimates differ, both for the world TFR and for the population peak.

[3] Only about 72% of a year's births in Mexico are registered in the year they occur, and the rest are registered over the following years. The 2025 figure extrapolates the births registered within 2025 to an expected final tally.

[4] Many of these countries also send large numbers of emigrants. Colombia and Spain share an ultra-low fertility of around 1.0 to 1.2, but Colombians are moving to Spain, which cushions aging in Spain and accelerates it in Colombia.

and fertility, one of the oldest regularities in demography (Jones et al., 2010), flattened in the U.S. between 1980 and 2010, a phenomenon that seems to be spreading to other countries (a similar statement holds for the relation between fertility and education). Even more surprisingly, Doepke et al. (2023) document how the cross-country correlation between the TFR and the female labor force participation rate has also become positive in the OECD data.

To organize these facts, we estimate a single-factor model of the TFR for 236 countries and territories from 1950 to 2023. The estimated common factor peaks in 1978 and has been declining since. But the main driver of the fall in TFRs is the country-specific trends: 219 of the 236 countries carry a negative trend, averaging -0.062 births per woman per year, with no sign of leveling off within the sample. What has grown is dispersion: countries are passing through the demographic transition at different times, and the distance between those that have finished and those that have barely started keeps widening.

Unfortunately, we do not understand the mechanisms behind this fast drop in fertility, or its concentration among lower- and middle-income countries and among the poorest and least educated women within them. A classical quality-quantity trade-off has serious difficulties matching these observations: it is hard to find movements in the skill premium over the last decade large enough to do the work. This is not to say that the trade-off has stopped operating. Rather, no plausible calibration delivers a 35% fall in births in ten years, as in Colombia, through that channel alone. Country-specific mechanisms (poor labor market prospects for the young, high housing prices, contraceptive use, childcare availability) often help account for the timing and speed of a fertility decline. But they fail to account for the global dimension: we would need dozens of them all operating at once in the same direction.

Part of the difficulty is that the bar any explanation has to clear is lower than it looks, because children come in integers. A cohort in which 15 women in 100 remain childless, most have two children, and one mother in six has three or four delivers a completed fertility of 1.8. Raise childlessness from 15 to 26, move 13 more women to a single child, and empty out the four-child families, and the same cohort delivers 1.3, the conventional threshold for lowest-low fertility despite three-quarters of women behaving exactly as before. Small changes in relative prices or opportunity costs, applied at the margin, are enough.

Three popular candidates to account for the fall in fertility are shifts in preferences and social norms, smartphones and their effect on in-person interaction, and rising housing prices. It is too early to adjudicate among these. But, in our reading, smartphones accelerate the change in the TFR more than they cause it, and housing prices have an ambiguous effect because they make owners richer and renters poorer. We are left with shifts in preferences and social norms more by elimination than by conviction.

Thus, we will conjecture a more speculative possibility: modernity itself. We live in a society built around large organizations and formal credentials, which makes a third child expensive and childlessness cheap, and that circumstance has created a mismatch between women's position outside the home and men's inside it. As modernity has spread everywhere, even to countries with low income per capita, fertility has also fallen everywhere.

Not knowing the causes, we cannot forecast fertility over the coming decades. And forecasting is the easy part in comparison with designing policy. Economists are used to markets that correct themselves, but nothing in an economy pushes fertility back to replacement.

The economic consequences of these demographic forces are large. As the total labor force starts falling, the trend growth of GDP decreases mechanically. Even if total factor productivity (TFP) growth remains the same, which is unlikely, countries will move to a "new normal" of very slow economic growth. Debt service, pensions, and health care come out of aggregate output, not out of ratios.

None of this is idle speculation. Japanese GDP grew at 0.79% a year from 1991 to 2023, far below the 2.60% of the U.S. But once we control for demographics by looking at GDP per working-age adult, Japan grew at 1.33%, not much below the 1.73% of the U.S. And Japan may be the best-case scenario: it has a homogeneous population, it is well governed, and it is rich. Countries such as Mexico or Tunisia will face the same demographic pressures with less consensus, far weaker states, and lower income per capita.

However, not all the consequences of a fall in fertility are bad. For example, teenage pregnancies in the U.S., most of them unintended, fell by 71% between 2007 and 2024. Slower population growth eases pressure on infrastructure, housing, and emissions, and gives emerging economies a window to educate smaller cohorts better.

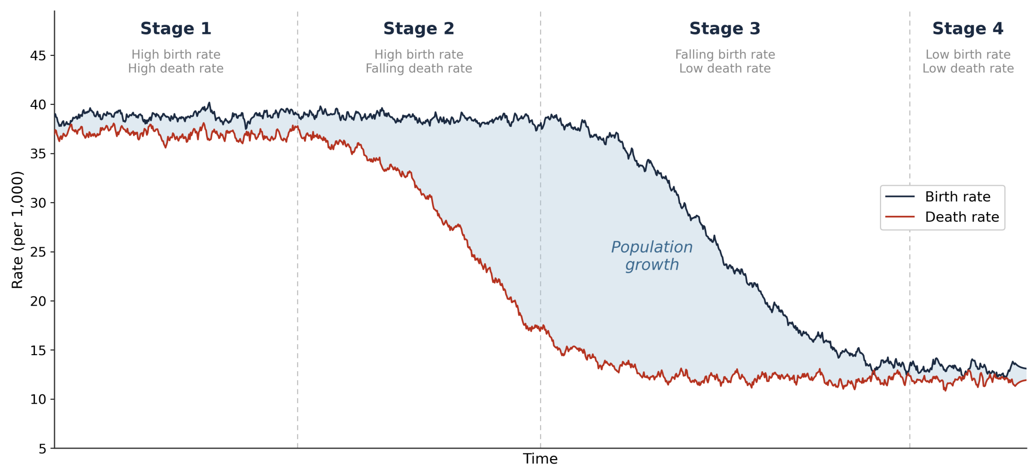
The rest of the paper is structured as follows. Section 2 describes the canonical demographic transition. Section 3 turns to the arrival of ultra-low fertility. Section 4 presents a single-factor model to account for the data. Section 5 discusses the possible mechanisms behind ultra-low fertility. Section 6 outlines the economic consequences of low fertility. Section 7 concludes.

Three sections of Supplemental Material provide further details.

2 The canonical demographic transition

Courses on demography or population history usually open with the canonical demographic transition model: the shift from high fertility and high mortality to low fertility and low mortality.[5] Figure 1 summarizes this pattern in four stages.

Figure 1: The canonical demographic transition



NOTES: The blue line shows the crude birth rate (CBR); the red line shows the crude death rate (CDR). Stage 1 is the demographic ancien régime, Stage 2 the fall in mortality, Stage 3 the fall in births, and Stage 4 the new low-fertility, low-mortality regime. The shaded area between the two lines is the growth of population.

For most of human history, the so-called demographic ancien régime of Stage 1, the crude birth rate (CBR) ran between 30 and 40 per thousand, with death rates only slightly below. A CBR of 30 per thousand corresponds to a TFR of around 4.6, and a CBR of 40 to a TFR of around 6.1. Take England, well documented thanks to the population reconstructions of Wrigley and Schofield (1981) and Wrigley et al. (1997). The English CBR was near 31 per thousand around 1700, with a TFR near 4.5, rising to about 40 per thousand and a TFR near 5.9 by 1815. Even at this peak, the English were far from the biological maximum, a TFR of around 9 or 10.[6] The reason was the European marriage pattern: women married at 25 or 26, and 10 to

[5] Livi-Bacci (2025) is a deft introduction to population history and Chesnais (1992) and Lee (2003) provide clasical descriptions of the demographic transition.

[6] This maximum comes from data on the Hutterites, an Anabaptist group in the northern Great Plains and western Canada who married early, used no contraception, and enjoyed good nutrition and health care. Eaton and Mayer (1953) found a completed fertility rate (CFR) of 10.4 children in the 1940s. Demographers have used

15% never married (Hajnal, 1965, Clark et al., 2024).

Mortality was nearly as high. Life expectancy at birth was around 35, but that figure is dominated by deaths in the first years of life. A child who made it to 15 had a fair chance of reaching her early fifties.

Births and deaths moved in cycles tied to climate, economic conditions, and other forces, roughly following a Malthusian logic (Clark, 2007). But most populations stayed near a CBR of 30 to 40, so population grew slowly over the millennia, with bursts of faster growth when conditions were favorable and long spells of decline when they were not.

The demographic transition began in the late 18th century in France and Britain, when mortality fell, Stage 2 of Figure 1. Births followed about a century later, in Stage 3, somewhat earlier in France, probably because of legal and social changes around the time of the Revolution (see Cummins, 2013, on changing inequality, Gay et al., 2026, on inheritance laws, and Blanc, 2023, on secularization). This led to fast population growth for around 150 years, much of it channeled into outmigration. From France and Britain, the transition spread to the rest of Europe and, eventually, the rest of the world.

In earlier work, one of us documented that the countries starting later moved faster, compressing into a few decades what had taken Britain more than a century (Delventhal et al., 2021). On the eve of World War II, births had nearly caught up with deaths, and growth slowed. The postwar baby boom was a temporary reversal (Doepke et al., 2015), and by around 1980 most advanced economies had reached Stage 4, with CBRs between 11 and 15 per thousand, implying TFRs between 1.7 and 2.0, with 1.8 taken as the floor.[7] The Stage 4 death rate is low in part because the age structure is still young: the large cohorts born during the transition have not reached old age. As they do, the crude death rate (CDR) must rise mechanically, a point we return to in Section 3.

Economists understand this first major decline in advanced economies well, from 5 to 6 children per woman throughout most of human history to the levels of 1980 just described. Among the main drivers were a sharp fall in child mortality (the effective fertility rate, EFR, was often close to 2) and the shift from a low-skill, rural agrarian economy to a high-skill, urban

their age-specific rates ever since as the benchmark for maximum natural fertility, even if almost no historical population has come close to it.

[7]A few advanced economies were already slightly lower by 1980. The lowest, according to WPP 2024, was Denmark at 1.54, but these were seen as anomalies rather than the norm.

industrial one. We have quantitative models that fit these facts well (Galor and Weil, 1999, 2000, Fernández-Villaverde, 2001, Greenwood and Seshadri, 2002, Doepke, 2004, Cervellati and Sunde, 2015, Manuelli and Seshadri, 2009, Galor, 2011, Delventhal et al., 2021, Galor, 2025).

These models, while emphasizing a common global driver, leave scope for country-specific factors (Beach and Hanlon, 2023). Proximity to low-fertility neighbors accelerated Hungary's decline, and inheritance laws accelerated France's. But these were second-order mechanisms.

This is also why most economists long considered doom scenarios of a population explosion à la Ehrlich (1968) implausible. We expected fertility in middle- and low-income economies to follow the same path as in the rich world, probably faster, because reductions in child mortality reached India and Africa at lower income levels (medical technology is nearly universal, and most gains come from handwashing and cheap antibiotics, not Mayo Clinic-level care). Much of the decline in Africa or parts of Latin America today is still that old story: falling infant mortality and the quality-quantity trade-off doing its work.

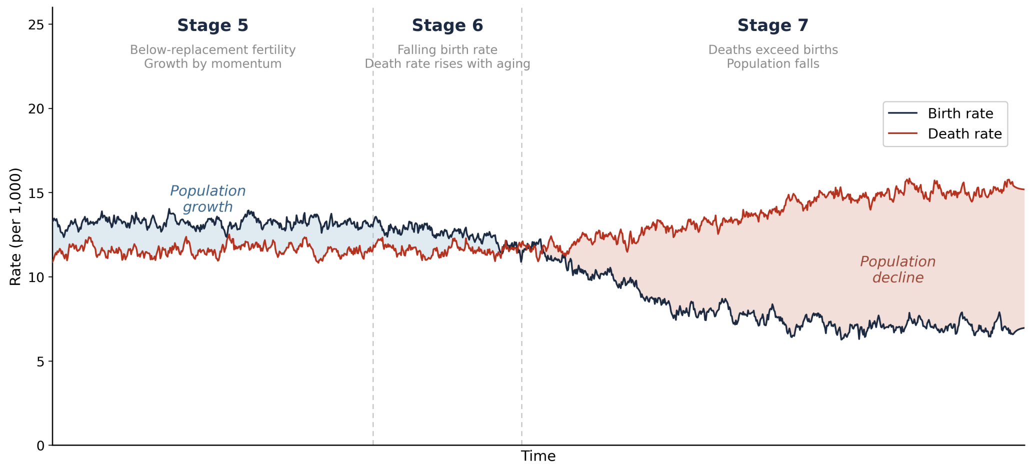
That is the story we knew how to tell, and we told it with confidence. Fertility would fall to around the replacement rate and stop there (Bongaarts, 2002).

3 The second demographic transition

But in the second half of the 1980s, a new pattern appeared: countries fell below replacement rate by wide margins. Japan and Italy are the paradigmatic cases. Driven by expensive housing, unbalanced gender norms, and poor labor market prospects for the young, Japan's TFR stood at 1.54 and Italy's at 1.36 by 1990 (Retherford et al., 2001, Del Boca, 2002, Feyrer et al., 2008).

While this second fertility decline began earlier in some countries for idiosyncratic reasons, we will argue in Section 5 that the underlying forces were common to many societies: secularization, an education arms race, expensive housing, the dissolution of kin networks, and the shift to a service economy in which women's bargaining power within the household is higher. This is Stage 5 in Figure 2. At the same time, as we anticipated above, the death rate started growing mechanically because of population aging, which brings us to Stage 6. Demographers call the whole phenomenon the *second demographic transition* (Lesthaeghe, 2010). Figure 2 shows the CBR falling to 5-7 per thousand while the CDR climbs to 12-13, opening a large gap of population decline in Stage 7 (ignoring migration).

Figure 2: The second demographic transition



Notes: Stage 5 is below-replacement fertility with growth sustained by momentum, Stage 6 the rise in the death rate as the population ages, and Stage 7 the crossing at which deaths exceed births and population falls.

Many missed the strength of this second demographic transition for two reasons. First, the U.S. lagged behind. Secularization came later than in other Western countries, suburban housing remained relatively cheap, and fertility among African American and Hispanic women was still well above the national average. U.S. demographic patterns are often exceptional among advanced economies, and they skew how academics, most of whom sit in the U.S., see the world.

Second, given the suddenness of the drop in fertility, standard datasets may lag behind the most recent developments.[8] According to the most recent revision of the WPP, released in July 2024, world population is likely to peak in 2084 at 10.29 billion people. This is the "Medium Variant" scenario, the mean of several thousand projected trajectories and by far the most used.[9] So why have we claimed that world population is likely to peak in the 2050s? In short, we are skeptical of the UNPD numbers. They seem to us systematically biased upward: they estimate and project levels of fertility and births that we find hard to believe. Supplemental Material B gives our reasons in detail.

Despite these problems, it became increasingly difficult to deny the reality of the second demographic transition. During the 1990s and early 2000s, Spain, Greece, South Korea, and

[8] Throughout this paper we often use "likely," "probably," and similar hedges. This is not a fondness for hedging, but a recognition that demographic data are often unreliable or subject to large revisions.

[9] The WPP is really a collection of estimates (from 1950 to 2023 in the most recent revision) along with various projection scenarios (from 2024 to 2100). Also frequently cited are the "Low Variant" and "High Variant," constructed from the "Medium Variant" by shifting the projected TFR series down and up, respectively, by 0.5 births per woman. The WPP also includes probabilistic scenarios and prediction intervals worth consulting, but these are cited less often and generally tell the same story.

China joined Japan and Italy in the ranks of what became known as lowest-low fertility, a TFR below 1.3 (Kohler et al., 2002). Over the last decade, Chile, Colombia, and much of the Caribbean have followed. Even advanced economies that had seemed resilient, such as the U.S. and France, have now fallen well below the old 1.8 floor.

The only clear exception is Israel. Its TFR stood at 2.86 in 2024, against 2.91 in 1991, roughly constant for 35 years. The stability is remarkable in itself, but the evolution within population subgroups is more striking still. The TFR of Jewish mothers has held steady, even among secular Jewish mothers, while the fertility of Muslim mothers has fallen fast. Since 2020, and for the first time since the founding of the State of Israel in 1948, the TFR of Muslims has been below that of Jews.[10]

Sub-Saharan Africa is the region where we can see the least about the recent trends in fertility. The data are of much poorer quality, and many reported TFRs are more guesswork than hard reality. But there are growing indications of a fast decline. For example, Institut National de la Statistique and ICF (2026) reports a drop in the TFR of the Republic of Congo from 5.1 in 2011-2012 to 3.5 in 2023-2025, a fall of 1.6 births per woman in less than a decade and a half. To put this in perspective, this TFR is lower than the "Low Variant" of the WPP by 0.3 births per woman. See Schoumaker (2019) for further discussion.

4 An empirical framework

To organize the data on world fertility, we estimate a single-factor model in the tradition of Lee and Carter (1992) that allows for common dynamics and country-specific components.[11] The TFR of country i at time t, $TFR_{i,t}$, depends on a country-specific fixed effect, α_i, and trend, δ_i, on a common global factor λ_t with a loading $\beta_{i,t}$ that varies smoothly over time, and on an idiosyncratic component $\epsilon_{i,t}$:

$$TFR_{i,t} = \alpha_i + \delta_i t + \beta_{i,t}\lambda_t + \epsilon_{i,t} \tag{1}$$

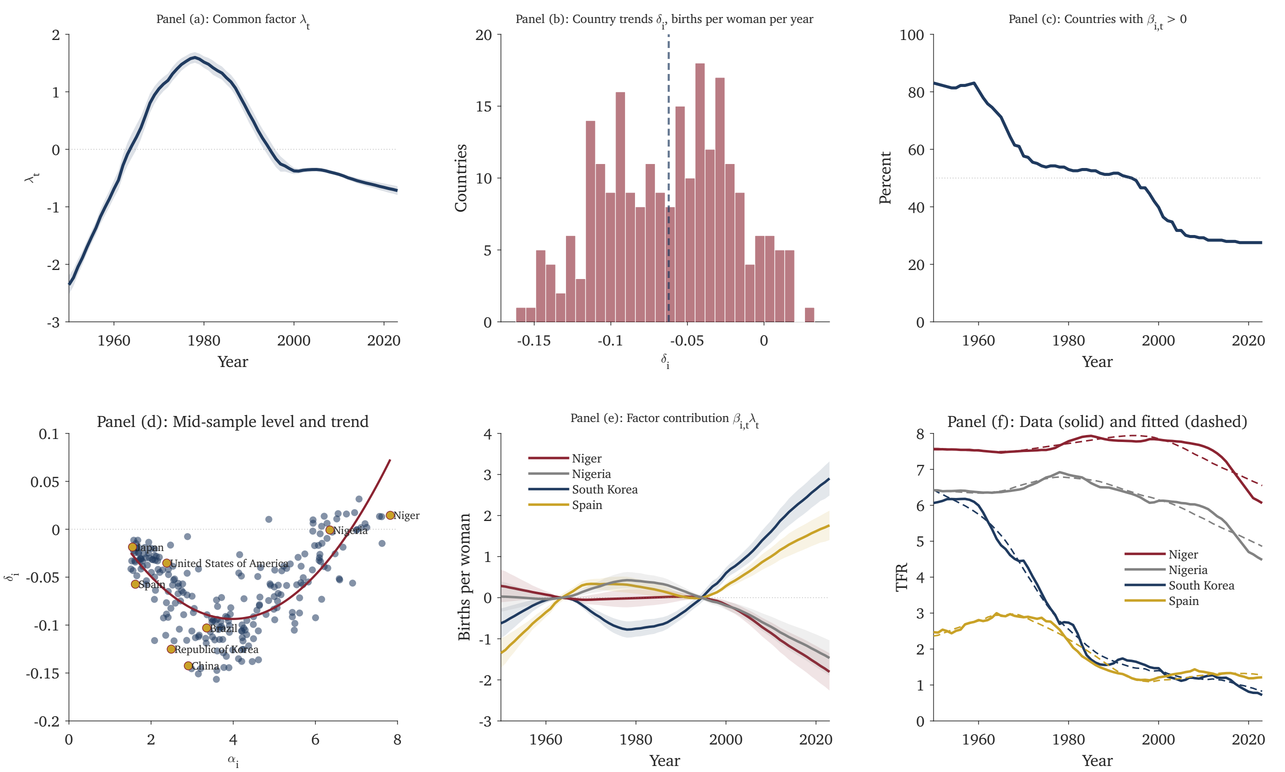
[10] Here we follow the population definitions employed by the Israel Central Bureau of Statistics. According to those, the TFR is computed for those living within the 1948 Green Line, the Golan Heights, East Jerusalem, and Jewish residents throughout the West Bank.

[11] This is, of course, an application to demographics of the factor model introduced by Geweke (1977) and Sargent and Sims (1977).

We let $\beta_{i,t}$ vary because the data reject a constant one. Estimating the restricted model with $\beta_{i,t} = \beta_i$ and splitting the sample in half yields loadings that correlate only 0.18 across the two halves. The reason is simple: countries enter their fertility transitions decades apart, and a fixed loading cannot capture a shift along the time axis. Supplemental Material C describes the algorithm required to take it to the data.

To do so, we use the TFRs from the WPP. Supplemental Material B criticizes some elements of this dataset, but it is the most cited set of global demographic data, and there is no good alternative: nothing else combines global estimates and projections, multiple data sources, and is updated every two years. Most other projections are based, implicitly or explicitly, on the UN numbers. The WPP gives us a balanced panel of 236 countries and territories, 1950 to 2023 (later TFRs are projections).

Figure 3: Common factor and heterogeneous trends in the total fertility rate



NOTES: Estimates of $TFR_{i,t} = \alpha_i + \delta_i t + \beta_{i,t}\lambda_t + \epsilon_{i,t}$ by local principal components with an Epanechnikov kernel of bandwidth twenty years, on a balanced panel of 236 countries and territories, 1950 to 2023, from the WPP. The trend is centered at the sample midpoint, so α_i is the mid-sample level.

Figure 3 collects our main results. Panel (a) plots the common factor $\widehat{\lambda}_t$ with a 95% moving-block bootstrap band. The factor climbs from -2.36 in 1950, its minimum in the sample, to

1.60 in 1978, which is not surprising since the average TFR, unweighted by population, did not start falling until the early 1960s. After 1978, $\widehat{\lambda}_t$ falls, quite fast at first, reaching -0.5 by the late 1990s, and drifting down more slowly since.

Panel (b) reports the distribution of the country trends $\widehat{\delta}_i$, in births per woman per year, with the cross-country mean of -0.0622 marked by a dashed line.[12] Only 17 of the 236 countries and territories trend upward, and none by much: Chad (0.0315), Ethiopia (0.0173), the Democratic Republic of the Congo (0.0163), Burkina Faso (0.0159), and Niger (0.0145) head the list, and every other member of the group except Afghanistan and Timor-Leste is also in sub-Saharan Africa. Both panels need to be read together. For a country with a positive $\beta_{i,t}$, as the large majority then had, the rise of $\widehat{\lambda}_t$ before 1978 means fertility falls more slowly than its own trend line, and the fall after 1978 means fertility falls faster.

Panel (c) explains why we let the loadings move in Equation 1. The share of countries with $\widehat{\beta}_{i,t} > 0$ falls from 83% in 1950 to 52% in 1990 and 28% in 2023, with 157 of the 236 countries switching signs at least once. A country with $\widehat{\beta}_{i,t} > 0$ lags the rest of the world in its demographic transition; one with $\widehat{\beta}_{i,t} < 0$ runs ahead of it. Forcing the loading to be constant means averaging over this movement; hence the poor half-sample correlation reported above.

Panel (d) plots the trends $\widehat{\delta}_i$ against the fixed effects $\widehat{\alpha}_i$. The scatter is U-shaped: a quadratic regression in $\widehat{\alpha}_i$ accounts for 55% of the cross-country variation in $\widehat{\delta}_i$, a straight line for a mere 4%, and the minimum falls near 4.0. This U-shape is largely mechanical. Countries at the low end had already fallen most of the way and had little room left, while those at the high end had barely started. Either way, the trend is small. The high end is almost entirely sub-Saharan Africa, where the canonical transition is still in its early stages (Delventhal et al., 2021). The fast declines belong to the countries in between, those with mid-sample TFRs between three and four and a half: Thailand (-0.146), Mongolia (-0.144), Tunisia (-0.144), China (-0.142), Algeria (-0.138), and Iran (-0.125).

Panel (e) plots the factor contribution $\widehat{\beta}_{i,t}\widehat{\lambda}_t$ for four countries: two with high fertility today, Niger and Nigeria, and two with low fertility today, South Korea and Spain. By 2023, the factor adds 2.90 births per woman to South Korea's linear path and 1.76 to Spain's; without it, their

[12]One could write the model with a global trend, $\alpha_i + \gamma t + \delta_i t + \beta_{i,t}\lambda_t$, but γ is collinear with the country trends and only $\gamma + \delta_i$ is identified. Imposing $\sum_i \delta_i = 0$ makes $\widehat{\gamma}$ the cross-country mean reported above, -0.0622, leaves the fitted values, $\widehat{\lambda}_t$, and $\widehat{\beta}_{i,t}$ unchanged, and gives deviations with a cross-country standard deviation of 0.0422.

linear paths would imply negative TFRs! Meanwhile, the factor subtracts 1.81 from Niger's TFR and 1.47 from Nigeria's. The dispersion of the contribution across countries follows the same pattern, falling from 0.86 in 1950 to 0.29 in 1990 and then rising to 1.60 in 2023. The common component does most of its work separating countries at the two ends of the sample and very little in the middle, when the demographic transitions were most nearly synchronized.

Finally, Panel (f) plots the data (solid) and the fitted values (dashed) for the same four countries. The model tracks most of the 236 time series closely: the median country R^2, computed after removing the level and the trend, is 0.967.

Figure 3 highlights three patterns. First, fertility is declining steadily nearly everywhere: 219 of the 236 estimated trends are negative, the average country loses about 0.062 births per woman per year, and nothing suggests these declines are leveling off. Second, the common factor resembles a bygone wave: it peaks in 1978 and shows little change over the past fifteen years. Third, the fastest declines occur in the countries at the bottom of the U in Panel (d): Thailand, China, Tunisia, Algeria, and Iran, which had TFRs between 3 and 4.5 around the middle of the sample and are losing roughly 0.13 to 0.15 births per woman per year.

Together, these patterns suggest that the increasing cross-country dispersion in fertility is driven less by a single global force than by countries moving through the transition at different times. The dispersion of the estimated factor contribution increases roughly fivefold after 1990, as countries that have largely completed the transition diverge from those only beginning it.

Therefore, any satisfactory explanation of the data must satisfy two criteria. First, it must deliver a nearly universal drop in fertility, since we have estimated that almost every country has a negative trend with no signs of leveling off. Second, it must deliver country-specific timing, since the dates of fast fertility declines differ by decades across countries. The next section asks which candidates can do both.

5 The mechanisms

This section has three goals. First, we highlight that lowest-low TFRs are not that hard to reach once we remember that children come in integers. Second, we explore the mechanisms proposed in the literature, asking of each whether it delivers the common direction and the country-specific timing that Section 4 requires. Finally, we point out that, unlike in other situations in economics, no feedback mechanism keeps the TFR at replacement level.

5.1 The unpleasant integer arithmetic of replacement fertility

The unpleasant integer arithmetic of replacement fertility is worth outlining, since it shows the range of choices that deliver lowest-low fertility.

Imagine a cohort of 100 women. Fifteen end up with no children, a share in line with the completed fertility of recent cohorts in Europe and the U.S. (Sobotka, 2017). Of those 15, around 5 are childless by choice, for professional, affective, or religious reasons; another 5 never find a partner or postpone childbirth until it is too late; and the remaining 5 want children but cannot have them for medical reasons, theirs or their partner's.[13] Of the remaining 85, 10 have one child, 60 have two, 10 have three, and 5 have four. We stop at four to keep the example simple; very few women in younger cohorts have five or more children, and the arithmetic could be adapted to include them.

The 100 women in this population have 180 children, for a CFR of 1.8, roughly the rate in many advanced economies until the early 1990s and in the U.S. until around 2008. And yet we are 30 children short of replacement. Look at what this population is doing: only 5 women in 100 choose to remain childless, three-quarters of all women have two children or more, and one mother in six has three or four. To reach 2.1, a population needs many families with three or more children. Families stopping at two do not deliver replacement.

Take another cohort, where the number of childless women rises from 15 to 26. Among the rest, 23 have one child, 46 have two, and 5 have three. None of the changes is dramatic: 11 more women at zero and 13 more at one. Three-quarters of women still behave as they did at 1.8, and the median number of children is still two, although barely. And yet completed fertility is now 1.3, the conventional threshold for lowest-low fertility.

Dropping from 1.8 to 1.3, then, is not a drastic change in most families. Any explanation only has to account for the quarter of women who switch, not for the 75% who do not. The key is that children come in integers. A woman at two may easily switch to one, or from one to zero, in response to relatively small changes in relative prices or opportunity costs. The integer

[13] About one adult in six experiences infertility at some point, and 12.6% of couples are infertile at any given moment (World Health Organization, 2023, Mascarenhas et al., 2012). Most of them eventually conceive, so permanent involuntary childlessness runs closer to 3 to 5% of women.

arithmetic of the replacement rate is unpleasant.

5.2 The possible explanations

Since we have seen how reaching lowest-low fertility does not require extraordinary rates of childlessness or very small families, we can turn to the mechanisms behind the recent drop.

Economic fundamentals. A first possibility is economic forces. The leading one is the quality-quantity trade-off à la Becker–Barro (Becker, 1960, Becker and Lewis, 1973, Becker and Barro, 1988, Barro and Becker, 1989).[14] Section 4 highlighted the role of country trends, and many of these are likely the trade-off kicking in around the world at each country's own pace. Delventhal et al. (2021) show how a Barro-Becker model can account for the timing of demographic transitions, including their acceleration, when augmented with a process of diffusion that biases technological change toward skilled workers (Lucas, 2009).[15] The idea is that modern technologies do not arrive everywhere at once: they diffuse away from the countries where modern economic growth started. This mechanism can account, to some extent, for the evidence in Section 4, though not for the suddenness of the fertility collapse in some countries.

A second economic force discussed by Bar et al. (2018) is the price of the parent's time. The negative relationship between income and fertility, one of the oldest regularities in demography, flattened in the U.S. between 1980 and 2010: high-income families started having more children, not fewer, than poorer families. The authors favor marketization as the explanation. Rich parents buy childcare and domestic services, and rising inequality makes those services cheap relative to their own time. Relatedly, Hazan et al. (2023) document that highly educated women, more likely to be childless than other women in 1990, had converged to the same childlessness rate by 2020. In other words, children are becoming a luxury good.

Housing is another often-cited economic force (for evidence on global housing prices, see Knoll et al., 2017). But its effect on fertility is more complex than it first appears. Rising house prices make homeowners wealthier, but they also make it more difficult for renters to buy a home or move into a larger one. Therefore, each group responds differently. Dettling and Kearney (2014) estimate that a $10,000 increase in local house prices raises births among homeowners by about 5% while reducing births among non-homeowners by roughly 2.4%. Since most U.S.

[14] Doepke and Tertilt (2016) survey how family decisions enter into standard macroeconomic models.

[15] See, also, for a related idea Galor and Mountford (2008).

households are homeowners, the overall effect is positive. Similar results appear in Denmark (Daysal et al., 2021). In comparison, Yi and Zhang (2010) document a negative effect of housing prices on fertility in Hong Kong, where real estate is extraordinarily expensive.

However, who owns houses has changed: the young are renters for longer than they used to be. Fazio et al. (2025), using Brazilian housing credit lotteries, find that winning a home raises the probability of having a child by about a third among 20 to 25-year-olds. Furthermore, families respond by moving to cheaper locations, undoing some of the effects of higher prices. Couillard (2025) accounts for this margin, combining census tract data with a structural model of housing demand and location choice, and finds that, had real housing costs stayed at their 1990 level, 13 million more children would have been born in the U.S. over the following three decades. He also estimates that building fewer large units generates 2.3 times more births than building a larger number of small ones.

In our reading of the evidence, the ultimate problem is that housing prices cannot account for fast drops in fertility in locations where real estate is cheap relative to income, such as in many rural locations.

Government policies. A second possibility is government policy. These explanations suffer from a common problem: we do not see large impacts, either in repressing fertility when governments want it lower or in raising it when they turn pro-natalist.[16]

Take China's one-child policy. Many have argued that it lies behind China's low TFR, even after the policy was lifted, perhaps through a persistent effect on social norms or the demographic balance. But we have Taiwan, a quasi-natural control group, with closely related culture and social norms and no one-child policy. In 1979, when China introduced the policy, Taiwan's TFR (2.67) was slightly below China's (2.80). In 2015, when the policy was lifted, Taiwan's TFR was 1.18 and China's 1.57. Not only had Taiwan's TFR collapsed, but it had also fallen further than China's.

The evidence from Taiwan is not airtight. Taiwan developed earlier and adopted its own (milder) policies to lower population growth, and China's one-child policy had dozens of exemptions. Most of the population could claim at least one for much of the period, and enforcement in rural areas, where most Chinese lived, was lax. But the two are close enough for the comparison

[16]See, for different views, de Silva and Tenreyro (2017), de Silva and Tenreyro (2020), and Bergsvik et al. (2021).

to be informative, even if we cannot build a counterfactual China without the one-child policy. And the point goes beyond Taiwan. Plot the TFR of ethnic Chinese in Malaysia or Singapore, and you will have trouble telling the lines apart from mainland China's, and Chinese Americans are among the lowest-fertility groups in the U.S., though intermarriage makes that hard to measure. Something more fundamental is at work in East Asia (and populations of East Asian ancestry) than any concrete policy.

Also, China's case does not mean that pro-natalist policies are ineffective. Well-identified research designs find positive but small effects. Milligan (2005) exploits Quebec's Allowance for Newborn Children, which paid families up to C$8,000 for a third child, and finds a sharp rise in births positively correlated with the size of the transfer. Cohen et al. (2013) use variation in Israeli child subsidies and estimate a price elasticity of fertility near -0.5, concentrated among low-income households. González (2013) shows that Spain's universal baby bonus raised conceptions and lowered abortions. Laroque and Salanié (2014) estimate that French family benefits raise completed fertility by a modest amount. Raute (2019) finds that a German reform tying maternity benefits to previous earnings raised births among highly educated women, the group pro-natalists most want to reach.

There are two reasons for skepticism. It might all be timing, with the same children arriving earlier. And the policies might not pass a cost-benefit test. Still, the preponderance of the evidence is that the CFR responds positively to policies such as extended parental leave and cheaper housing. And, as Stone and Wingerter (2024) emphasize, differences in a CFR of 0.1 to 0.2, well within the range of credibly identified results, accumulate into very large differences in population over a few decades.

Preferences and social norms. This seems a good moment to turn to the third possibility, namely, changing preferences and social norms, including gender roles.

Different authors use these terms to include a variety of forces: the spread of individualism, secularization, women's liberation, less interest in marriage, lower desire for descendants, or the rise of a parenting standard that makes each child more expensive in terms of time and worry (Doepke and Zilibotti, 2019, Doepke et al., 2019, Nakakuni et al., 2026). Delventhal et al. (2021) document one version of these forces in what they call demographic contagion: the timing of a country's transition depends not only on economic fundamentals such as GDP per capita, but also on whether its neighbors have started their transition. Since neighbors are defined not only by geographical distance but by other cultural metrics, they interpret this result as the spread of social norms. Kearney et al. (2022) reach a similar conclusion with U.S. data, but by elimination. They examine and rule out unemployment, housing costs, childcare, contraception, and student debt as drivers of the recent fall in the U.S. TFR, and are left with a "Solow residual of fertility" that measures our ignorance, which they interpret as shifting priorities across cohorts.

Smartphones. Finally, a fourth possibility that has gained much traction lately is the role of smartphones, or social media more generally. Myers and Hooper (2026) exploit the fact that from June 2007 through February 2011 the iPhone was sold only by AT&T, and identify its effect from variation in that carrier's mobile broadband coverage. They estimate that the diffusion of the iPhone accounts for 33–52% of the decline in the general fertility rate among women aged 15–44. Unfortunately, this evidence is only for the U.S.[17] Hudson and Moscoso Boedo (2026) implement a similar design for England and Wales, and find the same effect of mobile coverage on teen conceptions.

Our reading of the evidence is that smartphones might have accelerated the fall in fertility, but the outcome would not have been much different because powerful trends were already at work. Take Italy. Its TFR was 1.19 in 1995. In 2025, it was 1.14.[18] That gives you a sense of how much scope smartphones have as an explanation.

Where smartphones or social media might have mattered is in the diffusion of social norms we discussed above. What would have taken 25 years now happens in 10. Social media are not the cause of fertility decline; other forces are. But they are a very fast accelerator. That is why they are a major part of the story behind Guatemala going from 3.8 children per woman in 2005 to 1.9 in 2025. Without smartphones, Guatemala would also have reached 1.9, just 20 years later.

Modernity. The surprising case of Guatemala's TFR collapse points to one final possibility: modernity. While we are aware that this view is more speculative than the mechanisms discussed so far (and what economists usually entertain), it deserves some space.

By modernity, we mean a society organized around formal institutions, specialized expertise, and large-scale systems of coordination. We are influenced here by Max Weber. He argued that

[17] Guldi and Herbst (2017) exploit a similar design with broadband internet access, also within the U.S.

[18] The TFR is cyclical due to tempo effects, so we do not read too much into the rise between 1995 and 2007 or the decline from 1.27 in 2019 to 1.14 today.

modern societies increasingly organize economic life, law, and government through calculation, impersonal rules, and bureaucracy staffed by trained specialists (Weber, 1930, 1978). Large, complex societies become manageable only because knowledge is standardized and detached from local custom, whether through mass education, expert systems, or the state's effort to make society legible (Gellner, 1983, Giddens, 1990, Scott, 1998). On the economic side, our use of the term modernity is close to Mokyr (2002), who argues that sustained economic growth became possible once useful knowledge was codified, accumulated, and widely shared.

Modernity is not simply another name for capitalism. If anything, the historical record points in the opposite direction. Fertility declined earlier and, often, more rapidly in socialist economies than in market economies. Hungary, for example, fell below replacement fertility in 1960, followed by Czechoslovakia in 1966. Both countries experienced modest and short-lived baby booms in the mid-1970s, but neither reversed the broader downward trend.

Our conjecture is that a modern society makes the third child expensive and childlessness cheap, even when GDP per capita is only a fraction of the frontier (i.e., the U.S. level). Children are expensive because a child must be equipped to function in a world of formal knowledge and credentials, which takes years of costly investment (Restuccia and Vandenbroucke, 2013, Doepke and Zilibotti, 2019). At the same time, children are no longer productive in the household, not even for smaller chores, having been replaced by "engines of liberation" such as the electric appliances now available even to poor households (this idea extends the intuition in Greenwood et al., 2005). Modernity also imposes tight career schedules, set by large-scale organizations, that collide with the biological clock and with the kin networks that used to share the work of raising children (Adda et al., 2017, Compton and Pollak, 2014). And modernity makes childlessness cheap, because an impersonal society imposes next to no penalty on those who have no children: pensions and health care do the work that sons and daughters once did (Boldrin et al., 2015), and lineage counts for little.

Goldin (2026) pushes this line further with an argument about a growing mismatch between genders. Modernity also changes gender roles unevenly. Women's opportunities expand rapidly through education, work, and greater independence, while expectations about housework and childcare often change more slowly (Goldin and Katz, 2002, Goldin, 2021). This is particularly true as economies shift toward services, where women's comparative advantages are better rewarded (Ngai and Petrongolo, 2017). The mismatch operates at both the extensive and the intensive margins: more women remain childless, and mothers have fewer children on average.

This argument is attractive because it explains why East Asia and now Latin America have such low TFRs. These are the societies where the gender mismatch is largest.[19] It also suggests an intriguing possibility: societies with highly unbalanced gender norms start with very high TFRs, as men impose their preferences (Ashraf et al., 2014), and end with very low ones, as women resist (Doepke and Kindermann, 2019, Doepke and Tertilt, 2018). A paradoxical reversal of demographic fortunes.

The combination of expensive children and cheap childlessness gets us well below replacement, perhaps to 1.4 or so; recall the unpleasant integer arithmetic above. When and how quickly each country arrives at 1.4 depends on how fast the process of modernization is (which is not necessarily the same as the level of GDP per capita; see Spolaore and Wacziarg, 2022). This gives us a nearly-universal negative trend but with growing heterogeneity, exactly as in our model in Section 4.

From there, countries move in either direction. Those with higher income, better work-family balance, more gender equality, cheaper housing, and less acute educational arms races (Ramey and Ramey, 2010, Seth, 2002), or that have a significant religious subpopulation (Berman et al., 2018) can climb back to 1.6 or 1.7. The U.S. has many, though not all, of these features (Baudin et al., 2015), and the pattern is consistent with the finding that fertility turns up again at the highest levels of development if gender equality is high (Myrskylä et al., 2009, Goldscheider et al., 2015).

Countries with the opposite bundle (lower income, no work-family balance, less gender equality, expensive housing, brutal educational competition, and rapid secularization) fall to 0.7 or 0.8. East Asia is the obvious example: China, Taiwan, and South Korea have all of these features at once. In short, modernity in its current form seems largely incompatible with replacement-level fertility.

5.3 The weaknesses of feedback mechanisms

Economists tend to trust markets because they contain self-regulating mechanisms, perhaps not perfect, but powerful. Shortages of supply raise prices, reducing the quantity demanded and

[19]The argument also explains why cash transfers accomplish so little while parental leave makes a difference. The binding constraint is not the price of a child, but who will do the work of raising them.

creating incentives for new suppliers to enter. Excess supply works the opposite way. Thus, we expect prices to end up close to our definition of market clearing. Nor is this only theory. In a classic work, Smith (1962) showed that double auctions converge to the competitive equilibrium with just a handful of traders who know nothing about the aggregate demand and supply curves. Gode and Sunder (1993) replaced the human traders with machines that bid at random subject to a budget constraint. Allocative efficiency still reaches almost 100%.

But there is no self-regulating mechanism that pushes fertility back to replacement level. There is no reason to believe, for example, that the positive consequences of a falling population (e.g., cheaper housing) will overcome the negative ones (e.g., lower economic growth, higher taxes to pay for social security) and restore a steady state. More pointedly, the two welfare theorems break down as soon as we work with overlapping generations models, where agents do not have infinite lives (Samuelson, 1958). Competitive equilibria in such economies are generically inefficient in the pure exchange case, and need not be Pareto optimal in general.[20] More broadly, Weil (2024) makes this point better than we do: the replacement rate has no special status as an attractor or a target, and nothing would push a society to settle there.

Only three forces could return a population to replacement: policy, whose best-identified effects are real but small; selection, as higher-fertility subpopulations become a larger share of the total (Galor and Moav, 2002, Collins and Page, 2019); and the changes in relative prices induced by a falling population (Jones, 2022). None of them works fast or ensures efficiency.

Finally, there is no sense in which Earth can self-regulate population, at least not in the short run. The Malthusian mechanism is real, but it works on a completely different time scale (Clark, 2007, Weil and Wilde, 2009, Ashraf and Galor, 2011). Whatever feedback loop the planet exerts on human numbers works over centuries. Nearly none of the fertility decisions of women in Seoul or Bogotá are determined by the availability of food or by mortality risk. And, as we discuss in the next section, the consequences for labor forces, pension systems, and public debts arrive within decades.

Note that we have explored these mechanisms, we turn to the economic consequences of

[20]The intuition is that generations far apart in time cannot trade with each other, so the economy behaves as if markets were incomplete. The precise reason is the double infinity of agents and dated commodities (Shell, 1971): the standard proof of the first welfare theorem requires a finite value of the aggregate endowment, and with an infinite sequence of generations that requirement fails. See, in addition, our discussion in Subsection 6.6 of efficiency with endogenous fertility.

these demographic changes.

6 Some economic consequences

Like all changes, the demographic shift we have documented will bring good and bad outcomes. Which ones predominate will depend on the policies countries choose.

6.1 The good news

Not all consequences of a fall in fertility are bad. Hudson and Moscoso Boedo (2026) document a 74% drop in teenage pregnancies in the U.S. between 2004 and 2024. Since around three-quarters of pregnancies among American teenagers are unintended (Finer and Zolna, 2016), much of this decline is welcomed (Kearney and Levine, 2012).

When population grows slowly or falls, it also becomes easier to design policies that keep natural resource use sustainable, and pressure on infrastructure, housing, and emissions eases along with it. Latin American countries could, for instance, redesign the cities that grew wildly, and often without decent services, during the demographic boom of the 1950s to 1980s (Davis, 2006, Glaeser, 2014). For emerging economies more generally, lower fertility opens a window of opportunity (Bloom et al., 2003, Ashraf et al., 2013). These countries can educate smaller cohorts better, rebuild their infrastructure, and, before population aging fully takes hold, enjoy some fiscal space to facilitate structural reforms.

And for the planet as a whole, lower fertility might ease the transition to net-zero emissions (Casey and Galor, 2017). Integrated assessment models take population as an exogenous input (Fernández-Villaverde et al., 2025), and their emission paths are sensitive to that input in ways the literature has rarely explored.[21]

[21] Against this argument, the fiscal pressures created by a fall in fertility might make it harder for countries to fund the transition to net-zero or to spend enough on environmental protection.

6.2 The accounting of demographics

But now we move to the basic accounting of demographics. Begin with a national accounting identity:

$$\underbrace{y}_{\text{output}} = \underbrace{\frac{y}{l}}_{\text{labor productivity}} * \underbrace{l}_{\text{labor}},$$

which in growth rates reads

$$\underbrace{g_y}_{\text{output growth}} = \underbrace{g_{\frac{y}{l}}}_{\text{labor productivity growth}} + \underbrace{g_l}_{\text{labor growth}}$$

These simple definitions discipline what we can expect.

Take the U.S. around 2000, and, to make the argument as transparent as possible, use round numbers close to the actual ones:

$$\underbrace{3.0\%}_{\text{output growth}} = \underbrace{2\%}_{\text{labor productivity growth}} + \underbrace{1\%}_{\text{labor growth}} \tag{2}$$

Equation 2 explains why most economists around 2000 considered 3% the standard for measuring economic performance.[22] When the economy boomed, with unemployment falling and labor growing faster than average, we saw 4% growth. When it was depressed, with unemployment rising and labor growing slower than average, we saw 2%.

Now take the U.S. around 2050, assuming that labor productivity growth remains unchanged and there is no net migration:

$$\underbrace{1.5\%}_{\text{output growth}} = \underbrace{2\%}_{\text{labor productivity growth}} + \underbrace{-0.5\%}_{\text{labor growth}} \tag{3}$$

Equation 3 shows how 1.5% becomes the new normal. A boom delivers 2.5%, a slump 0.5%. The Fed can do nothing about this with monetary stimulus, and neither can the federal government with fiscal packages. A shrinking labor force is not a shortfall in aggregate demand, but a drop in the long-run trend of potential output (Okun, 1962, Blanchard and Quah, 1989).

Japan shows what these equations look like in practice, and how they change our view of

[22] Table 1 below reports exact numbers from 1991 to 2023. Notice, however, that those already include lower labor productivity and population growth after 2005 or so.

Table 1: G7 plus Spain: Output and Population Growth Rates

1991-2023	Canada	France	Germany	Italy	Japan	Spain	UK	U.S.
GDP	2.40	1.56	1.27	0.79	0.79	1.92	2.13	2.60
GDP per capita	1.26	1.07	1.14	0.67	0.78	1.24	1.56	1.69
GDP per work.-age adult	1.38	1.28	1.41	0.92	1.33	1.28	1.63	1.73
GDP per hour worked	1.09	1.07	1.37	0.67	1.22	0.58	1.45	1.62
GDP per worker	0.91	0.82	0.90	0.48	0.62	0.39	1.34	1.55
Population	1.12	0.49	0.13	0.12	0.01	0.68	0.55	0.90
Working-age adults	1.00	0.28	−0.14	−0.13	−0.53	0.63	0.48	0.85
Total hours worked	1.34	0.50	−0.10	0.14	−0.43	1.35	0.66	0.98

NOTES: Average annual growth rates in percent, 1991-2023. Working-age adults are those aged 15 to 64. Figures in red mark the Japan and U.S. comparisons discussed in the text.

economic performance. Table 1 reports average annual growth rates in percent, 1991-2023. We can plug in numbers for Japan and the U.S. in different ways, but the easiest way is to use data per hour worked:

$$\underbrace{0.79\%}_{\text{Japan's output growth}} = \underbrace{1.22\%}_{\text{Japan's labor productivity growth}} + \underbrace{-0.43\%}_{\text{Japan's labor growth}}$$

$$\underbrace{2.60\%}_{\text{U.S. output growth}} = \underbrace{1.62\%}_{\text{U.S. labor productivity growth}} + \underbrace{0.98\%}_{\text{U.S. labor growth}}$$

Now let us switch labor growth between the two countries and build a counterfactual where labor productivity growth remains unchanged but demographics do not:

$$\underbrace{2.20\%}_{\text{Japan's counterfactual output growth}} = \underbrace{1.22\%}_{\text{Japan's labor productivity growth}} + \underbrace{0.98\%}_{\text{U.S. labor growth}}$$

$$\underbrace{1.19\%}_{\text{U.S. counterfactual output growth}} = \underbrace{1.62\%}_{\text{U.S. labor productivity growth}} + \underbrace{-0.43\%}_{\text{Japan's labor growth}}$$

The usual verdict of a stagnant Japan and a booming U.S. gets reversed! Instead of the U.S. leading Japan by 1.8% a year, the U.S. now lags Japan by 1.0%. The U.S. still does better in productivity, but this is no longer a story of a stagnant Japan driven by poor policy choices (Pesek, 2014). It is a story of a U.S. that outperforms all seven other countries.

Now, the change in hours worked is not purely demographic: workers can move along both the intensive and the extensive margin. That is why we report changes in working-age adults and total hours worked. The results are the same because Japan and the U.S. increased their hours worked relative to the working-age population by roughly the same amount.[23] One can slow the effects of a shrinking working-age population for a while by getting more adults into the workforce or having them work longer hours. But eventually a country runs out of demographic space.

6.3 The future of labor growth

However, labor productivity is unlikely to keep growing at 2% as we assumed in Equations 2 and 3. Three reasons stand out. The first is the endogenous creation of ideas. The second is firm dynamism: an aging population starts fewer firms, and reallocation slows down. The third is the adoption of new technologies, which older workforces and older firms take up more slowly.

Let us start with ideas. Semi-endogenous growth models emphasize that the long-run growth rate of income per capita is proportional to the growth rate of the number of researchers (Jones, 1995). Since researchers cannot grow faster than population in the long run, smaller populations mean fewer of them. The logic runs deeper than mechanical accounting. Ideas are a nonrival good: smaller populations produce fewer ideas and spread their cost among fewer users. This is why Jones (2022) can show that an economy with permanently negative population growth converges to a path on which knowledge and living standards stop growing altogether, a result he calls the *empty planet*. The situation is worse because ideas are getting harder to find. Bloom et al. (2020) estimate that research productivity in the U.S. falls by roughly 5% a year. We need an ever larger number of researchers just to hold growth constant. Sadly, a country with a TFR of 1.2 will not have many pathbreaking scientists and engineers.

The loss is not just in the number of researchers, but potentially in the quality of the very best among them. In Fernández-Villaverde (2026), one of us compares South Korea's 1,080,535 births in 1960 with its 230,028 births in 2023 and asks what this 4.7-fold decline in cohort size implies for the most talented individual in each generation. With a Gaussian tail, the answer is: not much. The top child born in 1960 is expected to be 4.84σ above the mean, compared with 4.53σ for the top child born in 2023. Nearly a million additional births translate into less than one-third of a standard deviation at the very top. With a Pareto tail and $\alpha = 2$, the picture is

[23] Those who argue that many elderly Japanese work must remember that many elderly Japanese were already working already in 1991; one should not confuse a statement about levels with a statement about rates.

very different. The frontier scales with the square root of the cohort size, so the median of the cohort maxima in 1960 is expected to be 883 times the median person, against only 407 times in 2023.

However, the evidence on the returns to innovation points to fat tails (Scherer and Harhoff, 2000, Silverberg and Verspagen, 2007), and specific individuals matter beyond their number (Azoulay et al., 2010). If growth depends on a handful of exceptional innovators, it is the fat-tailed case that matters, and that is where shrinking cohorts hurt most.

Regarding business formation, Liang et al. (2018) document that a one standard deviation fall in median age buys 2.5 percentage points of new firms, some 40% of the mean rate. Hopenhayn et al. (2022) attribute the recent evolution of firm concentration, entrepreneurship, and the labor share in the U.S. to slower population growth. Likewise, Karahan et al. (2024) argue that demographic trends account for two-thirds of the decline in the start-up rate in the U.S. since the late 1970s, using the variation across states in the growth of labor supply that comes from fertility two decades earlier. Jones (2009, 2010) emphasizes that the education required to reach the technological frontier keeps rising, which compresses the innovative life cycle and reduces, everything else equal, aggregate creative output.

A more positive view appears in Acemoglu et al. (2026), who argue that the labor scarcity created by low fertility might induce labor-saving technologies. The argument is intriguing, but the variation the authors exploit is not informative about the fertility we face today. The lowest birth rate in their 1950 cross-section belongs to Austria, with a TFR of 2.09, essentially replacement; even in their 1980 panel the floor is Germany at 1.56. A TFR of 1.56 leaves 40% of the initial population after a century; a TFR of 0.75 leaves 3.5%, a factor of eleven. Both count as "low fertility" in a regression, yet they are different regimes. The authors say as much in their conclusion: changes this rapid lie outside the support of the historical evidence.

6.4 GDP per capita vs. total GDP

A reader may say that what we care about is output per capita, not output. Yes and no. Output per capita is the right measure of individual welfare. Hence, slower labor force growth costs us less than the headline numbers suggest. Japan has kept improving its living standards, and simulations for the U.S. suggest similar results (Weil, 2026).

But our capacity to service the public debt and to meet social security obligations depends on total output. Bondholders and retirees are paid in levels, not in ratios. And in a world of great-power competition, defense spending requires total output, not output per capita.[24]

These are just examples of a more general point: the second-round effects of a fall in fertility. More difficulty in servicing the public debt or meeting retirement benefit obligations might lead to inflationary pressures as governments try to monetize their debt. Real interest rates and housing prices might be directly affected. The distribution of population within a country might change too, with a few large "sponge cities" absorbing a dwindling population (Glaeser and Gyourko, 2005). We cannot explore these for reasons of space.

6.5 The political economy of aging

Many economists forget that the first-order problem of an aging society, one with high life expectancy and low fertility, is how to redistribute income from workers to retirees. How fast output grows is, surprisingly enough, the lesser question.[25]

If an economy has roughly as many retirees as workers and we want to keep approximate parity of income, what each worker produces must be split in two: one part for the worker, one part for the retiree. It does not matter whether we do it through taxes, as in a pay-as-you-go pension system, or through capital income, as in a fully funded one. Workers will not be happy to see so much of GDP channeled to retirees.

This redistribution is likely to poison the political system and, with high probability, lead to dysfunctional policies over time. We are already seeing it across Western Europe in the fights over retirement benefits (Boeri et al., 2001, Galasso and Profeta, 2004), which make structural reform harder. And much of the American unhappiness about the profits of large corporations, largely owned by the old, is the same conflict, only in the fetishized form of equity ownership.

In fact, one could argue that the slowdown of growth in Japan we documented above is the best-case scenario. Japan is a homogeneous society with high levels of consensus, strong institutions, and high income per capita. It is hard to imagine how countries such as Mexico or Tunisia, with low-capability states and a tradition of political conflict (Besley and Persson,

[24] This is so even if we recognize that an economy with higher output per capita finds it easier to devote resources to defense, since it sits farther from binding constraints on consumption.

[25] Strictly speaking, aging is not the same as a fall in fertility: a population can age through rising life expectancy even with constant fertility (Weil, 1997). We skip this nuance for reasons of space.

2011), will handle the same demographic pressures in 30 or 40 years.

Claims of the form "technological progress (e.g., advances in AI well outside historical improvements in TFP growth) will fix the problems brought by aging" miss the political economy of the situation. The redistribution issues associated with aging are much more about politics than about productivity growth.

6.6 The welfare of pro-natalist policies

We close this section with a subtle point, well beyond the scope of this paper: the goal of economic policy in a model where population is endogenous. The philosophy of population size is a complex field. See Broome (2004) for an introduction accessible to economists; Parfit (1984, Part IV, chapter 17) for the classic treatment, including the *Repugnant Conclusion*; and Adhami et al. (2026) for what happens to measured welfare growth once we count people as well as consumption per person. Furthermore, once fertility is an endogenous choice, the meaning of efficiency has to be redefined, since the set of people whose welfare we are counting depends on the allocation itself (Golosov et al., 2007).

7 Concluding remarks

When one of us starts his undergraduate course on world economic history, he motivates the semester by arguing that history teaches us lessons about today's economy. Unfortunately, that is not true of population. We are entering demographic *terra incognita*: we have never seen TFRs as low as today's.

Will they recover? We do not know. Based on the data available as we write these lines, our best guess is a small rebound from tempo effects, but, short of a large change in society, not much more (see, for a similar assessment, Geruso and Spears, 2026). East Asia is likely stuck near 1, given its unbalanced gender norms and toxic education systems. Latin America faces the same gender problem plus weak growth prospects, so we expect something around 1.2. Northern Europe has more egalitarian family structures and might hold near 1.5. The very religious societies are probably the only ones that will sustain 1.8. Within countries, the higher-income and more educated will have more children than the lower-income and less educated.

These trends, if unchanged, will translate into large changes in world population and its distribution, both between and within countries. We may end up in a shrinking world where the very rich nations have the highest TFRs, and even those will be below replacement level.

All of this could change with AI or shifts in population composition. We will see. But on the current evidence, deep sub-replacement fertility is the "new new normal," and unless we find a way to reorganize our societies, we had better learn to handle it as best we can. We do not have a map. What we have birth numbers, and those are sobering. In these waters, the pretense of knowledge is the most dangerous temptation.

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Supplemental Material

A Some basic concepts in demographics

This Supplementary Material sets out the basic demographic concepts the paper uses. Readers with some background can skip it. Nothing here is new: our goal is just to provide a shared vocabulary.

First, some definitions. The crude birth rate (CBR) is the number of births per thousand inhabitants in a population in a year. The crude death rate (CDR) is the same measure for deaths. Both rates appeal for two reasons. They are easy to compute wherever vital statistics registers exist, as they have in some European countries, such as England and Sweden, for centuries (the English parish registers run from 1538, and Sweden's Tabellverket, the first true national vital statistics system, starts in 1749). They also provide a quick snapshot of a population's demographic situation.

The total fertility rate (TFR) is the average number of children a woman would bear if i) she faced current age-specific fertility rates throughout her life, and ii) she survived through ages 15-49, the fertile span for most women.

The TFR tells us less than the completed fertility rate (CFR), the average number of children actually born to a cohort of women. Completed fertility tells us how many children the average woman born in the U.S. in 1960 had by the end of her fertile life. The TFR is, instead, constructed by summing the period's age-specific fertility rates across reproductive ages. That is, the TFR assumes that a woman will go through her childbearing years having the same average number of children as women born in 1977, 1978, ..., 2011 did in 2026.

We use the TFR rather than the CFR because the CFR, by construction, arrives with a long lag. The price is that the TFR reflects tempo effects (Bongaarts and Feeney, 1998): if women born in 2000 bear children at different ages than those born in 1990, we may misread fertility. If women born in 2000 end up with the same number of children but bear them later, the TFR measured in real time will run below the CFR for years.

The TFR is important because it governs whether a population is above or below the replacement rate: whether enough children are born to sustain population levels (ignoring net immigration).[26]

The replacement level can be approximated as follows

$$\text{Replacement rate} \approx \frac{1 + \text{sex ratio at birth}}{\text{Probability of a woman surviving to 30}}$$

The previous equation tells us that a population of 100 women in an advanced economy needs 210 children to replace itself. Why? Absent sex-selective practices, roughly 105 boys are born for every 100 girls (the sex ratio at birth). Evolution overshoots male births because boys are more prone to early death from accidents and disease. Therefore, of 210 children, about 108 are boys and 102 are girls. Not all girls reach the midpoint of their fertile age: accidents, suicide, homicide, and illness take some. In an advanced economy, about 98% of them survive, leaving 100 women to replace the original 100. This is why most of the public discussion uses 2.1 as the replacement level.

However, 2.1 is not the replacement level for many countries (Espenshade et al., 2003). Think about a country like India c. 2005, with both selective abortions and high child mortality. India's replacement rate was:

$$\text{Replacement rate, India c. 2005} \approx \frac{1 + 1.10}{0.90} \approx 2.33$$

For the world as a whole, the replacement rate in 2026 lies between these two cases. The global sex ratio at birth is about 1.07, still above the biological norm of 1.05 because China and India account for such a large share of world births and in both the ratio is well above 1.05, although the gap is closing. Global under-five mortality has fallen to about 37 per thousand, so roughly 94% of girls born today survive to age 30. Those who die early, moreover, are concentrated in populations with a high TFR, which our simple approximation does not fully capture. Hence:

$$\text{Replacement rate, world} \approx \frac{1 + 1.07}{0.94} \approx 2.20$$

The world therefore needs a TFR near 2.2 to hold its population constant, not the 2.1 of the rich countries. The gap looks small, but as we will discuss below, it matters.

[26] From the previous paragraph, it is more precise to say that it is the CFR that governs whether a population replaces itself. We follow the common practice by talking about TFR, but let us not forget this warning.

Finally, we have the effective fertility rate (EFR): the average number of children per woman who survive to adulthood, that is, the TFR multiplied by the probability of surviving from birth to age 15 (Malani and Jacob, 2024). The EFR matters because population growth depends on the children who reach reproductive age, not on the children born. Before the modern decline in mortality, nearly half of all newborns died before age 15, so a TFR of around 5 delivered an EFR of only 2.5, barely above replacement (Volk and Atkinson, 2013). Child mortality has fallen so far over the last few decades that the two measures now almost coincide in high-income countries. In sub-Saharan Africa, the difference between the TFR and the EFR is still relatively large, but the gap is closing.

Population momentum keeps a population growing after fertility has fallen below replacement. This is due to the inertia of past generations. There are many women of childbearing age around the world and, even if on average they do not have enough daughters to replace themselves in the next generation, population keeps growing for some years.

An example illustrates this "inertia." Imagine two couples: the Smiths and the Browns. The Smiths have two sons and the Browns two daughters. And, by chance, the two Smith sons marry the two Brown daughters. The two happy new couples have only one child each. Since the grandparents have not died yet, the Smith-Brown population has grown from eight (the four grandparents and the four children) to ten (the four grandparents, the four children, and the two grandchildren). But the Smith-Browns are not replacing themselves: when the grandparents die, the Smith-Brown population will fall to six. Well, that is exactly what is happening on the planet right now: the grandchildren have already arrived, but the grandparents, who outnumber them, are still alive.

Before moving on, notice that momentum works through the age structure. Tempo effects, which we discussed above, work through the timing of births.

We need two more concepts before closing this Supplementary Material. The first is the old-age dependency ratio, which measures how many people aged 65 and over there are for every 100 people of working age (15 to 64). The second is the support ratio, or the number of working-age people supporting each retiree, which is simply the inverse of the old-age dependency ratio. Interestingly, neither of these measures relies much on assumptions about the future. Everyone who will be 24 or older in 2050 has already been born. Think about it in this way: in most countries, students graduate from college between the ages of 21 and 23. That means that nearly all of the pool of potential college graduates in 2050 has already been born. At the same time, nearly everyone who will hold a Ph.D. in 2050 has been born already.

In terms of life expectancy, researchers like to distinguish between life expectancy at birth, e_0, and life expectancy at age 65, e_{65}. In the early phases of the demographic transition, gains in e_0 were driven mainly by falling child mortality. More recently, increases have come largely from people living longer at older ages. This has large consequences, for example, for the sustainability of social security systems.

One last warning. Everything so far treats a population as closed. The complete balancing equation is births minus deaths plus net migration. For the planet, net migration is obviously zero (at least for the moment!). For any single country, it is not. A typical example is the U.S., where slightly different assumptions about net migration have large impacts on medium-run forecasts.

B Global demographic data

In the main text, we mentioned that we are not entirely convinced by the WPP numbers. To understand our position, note that the UNPD's birth numbers are generated from estimated and projected TFRs for 1950-2100. The TFR series for each country and region is built in two stages: first, estimation of historical TFRs from 1950 to the present using a variety of empirical sources (civil registration and vital statistics, censuses, demographic surveys, administrative records); second, projection of future fertility to 2100. In the 2024 revision, estimates run from 1950 to 2023 and projections from 2024 to 2100. Both stages use Bayesian hierarchical methods and rely to a nontrivial degree on analyst discretion. The methodology of the 2024 revision is described in United Nations (2024); for the machinery across revisions, see Ševčíková et al. (2011), Alkema et al. (2011), Alkema et al. (2012), Raftery et al. (2014), Ševčíková et al. (2018), Liu and Raftery (2020), Liu et al. (2023), Chao et al. (2023), and Ševčíková et al. (2026).

B.1 Discrepancies with vital statistics

Our first reason for questioning the WPP numbers is that they often overestimate births when compared with official vital registry systems.

In Table A1 we compare the WPP estimates of births in 2022-2023 with the official numbers reported by several countries.[27] We restrict attention to Colombia, Egypt, and Türkiye not because they are the only examples available, but because they are mid-sized countries with well-developed vital registration systems: the UN's own Population and Vital Statistics Report (United Nations, 2026b) rates all three as at least 90% complete.

Even restricting the analysis to three countries over two years, we find that the UNPD has overstated recent births by over one million. We emphasize again that this is not an isolated example; it looks to us like a systematic pattern of overestimation.

By itself, the UN's apparent distrust of official vital statistics is not a cause for criticism. The UN estimates are meant to be the "gold standard" of demographic data, and vital statistics are not always accurate. Official agencies can overreport or underreport births for lack of resources, through poor registration systems, or for political reasons. But recall that the UN's own records

[27] Recall that this revision of the WPP was released in July 2024, so the birth numbers given by the UNPD for 2022-2023 are *estimates* of past births, not *projections* of future births.

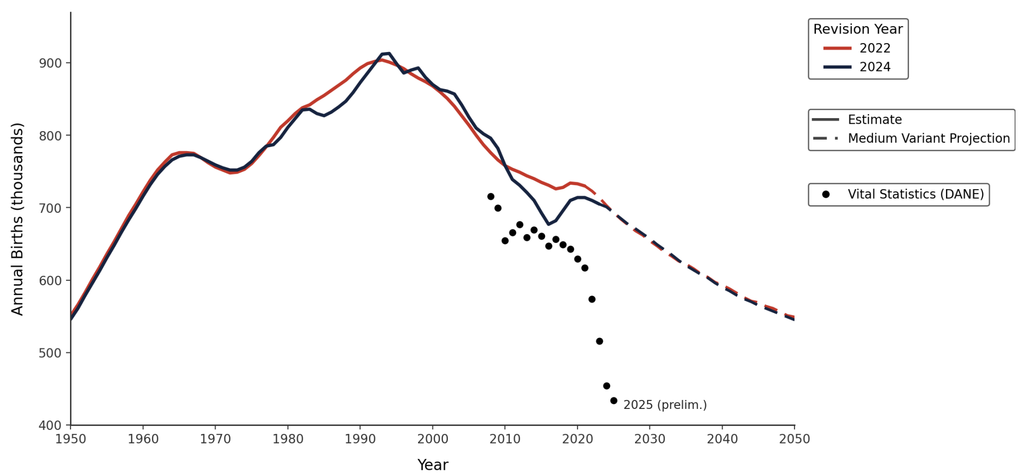
Table A1: Officially Reported Births and UN Population Division Estimates

Country	Year	Official births	UNPD estimate	Difference	% overestimate
Colombia	2022	573,625	710,000	136,375	23.8%
Colombia	2023	515,549	705,000	189,451	36.7%
Egypt	2022	2,192,947	2,375,000	182,053	8.3%
Egypt	2023	2,044,880	2,406,000	361,120	17.7%
Türkiye	2022	1,041,846	1,079,000	37,154	3.6%
Türkiye	2023	963,075	1,072,000	108,925	11.3%
Total		**7,331,922**	**8,347,000**	**1,015,078**	**13.8%**

NOTES: Official births from national statistical offices; estimates from the 2024 revision of the WPP. The percentage overestimate is the difference relative to official births.

rate the vital statistics registries of Colombia, Egypt, and Türkiye as over 90% complete (and these statistical agencies claim to be even much more accurate than that).

Figure A1: Estimated and projected births in Colombia: UNPD vs DANE



NOTES: The solid and dashed lines show the WPP estimates and projections of births in Colombia under the 2022 and 2024 revisions, respectively. The dots show annual births in Colombia from 2008 to 2025 as recorded by Colombia's national statistical office (DANE), as of August 2026. The 2025 figure is preliminary.

The point is made even more clearly in Figure A1, which compares the WPP estimated and projected birth series in Colombia with those from Colombia's vital registration system (Departamento Administrativo Nacional de Estadística (DANE), 2026). Despite the downward revision in the 2024 revision of the WPP, the new estimates do not go far enough to match the vital statistics. The projections of future births, furthermore, remained virtually unchanged despite the steep drop in DANE's series.

To understand how the UN justifies this discrepancy, we briefly outline how it constructs the estimated TFR series. The series comes from a Bayesian hierarchical model built on country-specific sources for total births in a given year. Because these sources vary widely in quality, across countries and over time, the UN estimates the bias of each source.

To do this, it chooses a source of birth data that it believes to be unbiased and then uses a set of covariates to predict the degree of bias in each of the other sources through a linear model. Neither the source chosen as unbiased nor the set of covariates is listed publicly, though the UN specify that "the fertility time series for countries with at least 98 per cent completeness of birth registration since 1950 were treated as unbiased." For countries lacking such complete vital statitics registries, "the model uses either the estimates from the previous revision of the *World Population Prospects* or some other data source(s) deemed unbiased by the analyst as a baseline reference." In proposing this methodology, Liu and Raftery (2020) recommend that the source taken to be unbiased should be the previous revision of the WPP.

Liu and Raftery (2020) also recommend using only time-invariant covariates, which rules out any improvement in the quality of vital statistics over time. The methodology report released with the 2024 revision, however, specifies that:

> ... the data used by the model to estimate and correct for biases are country-specific. The model uses either the estimates from the previous revision of the World Population Prospects or some other data source(s) deemed unbiased by the analyst as a baseline reference. The model takes into account two types of data characteristics: (1) several time-invariant categories that describe the type of data source (e.g., census, survey, vital registration), the type of estimation method (e.g., recent births, birth histories, adjusted fertility using P/F ratio method, own-children or reverse survival estimates, etc.), and the corresponding education level for estimates based on the reverse survival of enrolled schoolchildren, and (2) several time-dependent covariates such as the number of years of recall lag for retrospective estimates, the proportion of live births registered for vital statistics, the school enrolment rate for indirect estimates from education statistics, and the proportion of deaths due to conflicts or natural disasters one year prior.

It seems to us that if a country went from, say, 50% complete vital statistics registration in the 1950s to 99% complete in 2024, the UNPD's model would pick up the large error in the early years and carry it over to the later ones. This could seriously bias the estimates for countries that have developed significantly since 1950.

We believe that this is precisely what is happening in the countries in Table A1. The UNPD database shows that from 2019 onward, vital statistics are the *only* source it uses for births in Colombia. But if Colombia's registration system went from, say, 50% complete in the 1950s to 99% complete in 2023, the model picks up the large bias in the early years and carries it into the later ones. This biases the TFR estimates upward for countries that have developed significantly since 1950, and helps explain the large gaps between the recent births reported by the WPP and those reported by Colombia, Türkiye, and Egypt, countries the UN itself rates as having highly complete vital statistics registration.

Of course, the analysts always reserve the right to make adjustments, so there may be some futility in reading the methodology too closely.

B.2 Mean reverting projections

Our second reason for skepticism is that the WPP projections of future fertility rest heavily on a mean-reverting assumption we find implausible, given the arguments made in the rest of this paper.

To illustrate, we compare the 2024 birth totals projected in the most recent revision of the WPP with the *actual* 2024 births reported by vital statistics registries (United Nations, 2026a). All the countries in Table A2 are assessed by the UN as having at least 90% complete vital registries and have populations of at least one million. We sort them from largest overprojection to largest underprojection, in percentage terms.

These are not projections made 50 years out, where one might expect a high degree of uncertainty: they were published in July 2024. The asymmetry is the point. Only four of 37 countries had more births than the WPP projected, which is what we would expect if these numbers were systematically biased toward overstating births and fertility, and by extension total population.

To understand the source of this bias, we refer the reader to the detailed methodological

Table A2: Actual Births vs WPP Projections, 2024

Country	Actual births	WPP projection	Deviation (%)	Absolute gap
Colombia	445,011	701,000	−36.5	255,989
South Africa	787,933	1,183,000	−33.4	395,067
Singapore	33,703	49,000	−31.2	15,297
Cyprus	9,766	14,000	−30.2	4,234
Republic of Moldova	23,648	32,000	−26.1	8,352
Thailand	441,631	582,000	−24.1	140,369
Guatemala	299,256	380,000	−21.2	80,744
Poland	251,782	310,000	−18.8	58,218
Argentina	413,135	507,000	−18.5	93,865
Panama	59,729	72,000	−17.0	12,271
Albania	23,310	28,000	−16.8	4,690
Azerbaijan	102,310	121,000	−15.4	18,690
Türkiye	937,559	1,061,000	−11.6	123,441
Chile	154,441	172,000	−10.2	17,559
Uruguay	29,899	33,000	−9.4	3,101
Japan	686,173	751,000	−8.6	64,827
China, Hong Kong SAR	36,723	40,000	−8.2	3,277
Belarus	58,938	64,000	−7.9	5,062
Brazil	2,376,901	2,572,000	−7.6	195,099
Slovenia	16,875	18,000	−6.2	1,125
Switzerland	78,256	83,000	−5.7	4,744
Spain	318,579	333,000	−4.3	14,421
Australia	292,318	305,000	−4.2	12,682
Greece	68,309	71,000	−3.8	2,691
Russian Federation	1,222,408	1,270,000	−3.7	47,592
United Kingdom	659,628	684,000	−3.6	24,372
Netherlands	166,143	172,000	−3.4	5,857
Denmark	57,079	59,000	−3.3	1,921
Republic of Korea	238,317	241,000	−1.1	2,683
France	629,000	636,000	−1.1	7,000
United Arab Emirates	106,915	108,000	−1.0	1,085
United States of America	3,628,934	3,654,000	−0.7	25,066
Uzbekistan	926,422	929,000	−0.3	2,578
Canada	365,737	361,000	1.3	4,737
Kuwait	49,063	48,000	2.2	1,063
Bosnia and Herzegovina	24,598	24,000	2.5	598
Croatia	32,069	31,000	3.4	1,069
Total	**16,052,498**	**17,699,000**	**−9.3**	**1,646,502**

Notes: Actual births from national statistical offices; projections from the "Medium Variant" of the 2024 revision of the WPP, rounded to the nearest thousand. The table includes every country whose 2024 vital statistics registry data the UN deems at least 90% complete and whose population exceeds one million, sorted by percentage deviation. The total deviation of −9.3% is discussed in the text.

explanations in Alkema et al. (2011), Raftery et al. (2014), and Liu et al. (2023). Of particular interest here is how the UNPD models what it calls the "fertility transition regime" and the "low fertility regime," that is, countries that have begun and completed the second demographic transition, respectively.

Briefly, the "fertility transition regime" is characterized as a period of declining TFR, modeled as a random walk with drift:

$$f_{c,t+1} = f_{c,t} - d_{c,t}$$

where $f_{c,t}$ is the TFR in country c in year t, and $d_{c,t}$ is a stochastic decrement governed by a sum of double-logistic functions with country-specific parameters, estimated hierarchically by MCMC.

A country has entered the "low fertility regime" when, after averaging the TFR over five-year periods, two successive periods of increase are observed once the country has already fallen below 2.0 births per woman. This regime is modeled as a period of long-term stability, following a mean-reverting AR(1) process with a country-specific mean somewhere near replacement:

$$f_{c,t+1} \sim N(\mu_c + \rho_c(f_{c,t} - \mu_c), \sigma^2)$$

where μ_c is the country-specific long-run mean and ρ_c governs the rate of mean reversion.[28]

Again, both μ_c and ρ_c are estimated by MCMC, with the country-level mean drawn from $\mu_c \sim N(\bar{\mu}, \sigma_\mu^2)$, where $\bar{\mu} \sim U[0, 2.1]$ and $\sigma_\mu \sim U[0, 0.318]$.

The key feature driving the UN' results is the mean-reverting assumption of the low fertility regime. It is what produces rising projected TFRs even in countries with fast-falling fertility: South Korea rises monotonically from 0.72 in 2023 to 1.30 in 2100, China from 1.0 to 1.35.[29]

And as Table A3 makes clear, the UNPD models immediate mean reversion, no matter how fast or for how long the TFR has been falling in a given country. Despite rapid drops between 2018 and 2023, it generally projects either a stabilization or an increase over 2023-2028.

[28]This assumption originates in Lee and Tuljapurkar (1994) and is both justified and hedged for the current revision in United Nations (2024): "A long-term assumption of a fertility increase in low-fertility countries (phase III) is supported by the experience of many countries in Europe and East Asia... However, such an increase is not universal... For countries that have experienced extended periods of low fertility with no empirical indication of an increase in fertility, fertility was projected to continue at low levels in the near future"

[29]The UNPD does not make public the country-specific means to which these AR(1) processes revert. In earlier revisions, μ_c was assumed to be 2.1 for all c; the last several revisions have estimated a country-specific μ_c from the data.

Table A3: Immediate Mean Reversion in WPP Projections

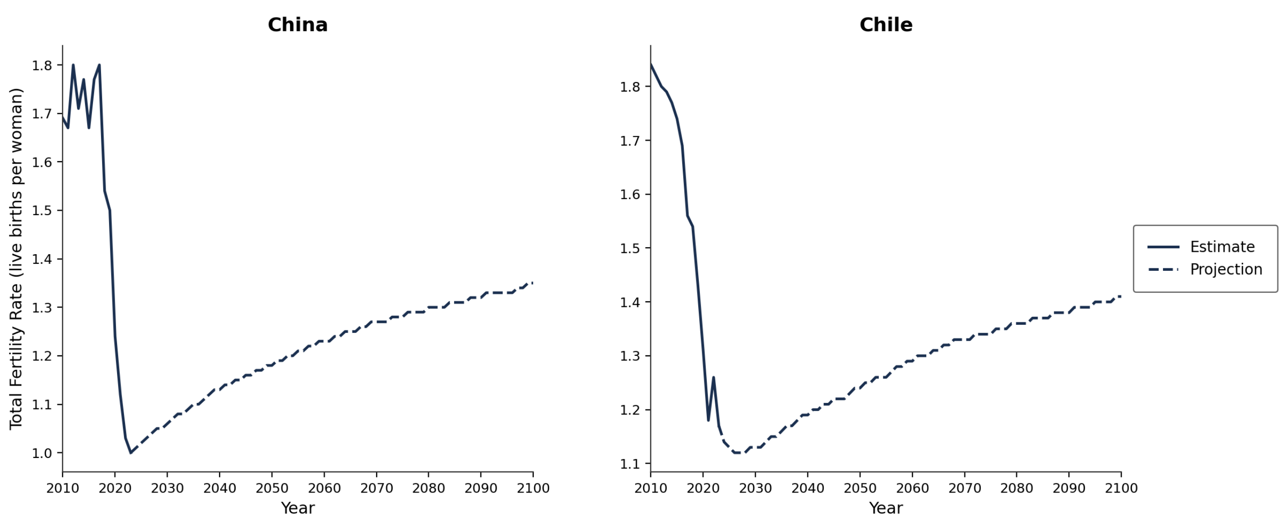
Country	TFR, 2018	TFR, 2023	Δ 2018–2023	TFR, 2028	Projected Δ 2023–2028
China	1.54	1.00	−0.54	1.05	+0.05
South Korea	0.95	0.72	−0.23	0.79	+0.07
Chile	1.54	1.17	−0.37	1.12	−0.05
United States	1.72	1.62	−0.10	1.63	+0.01
India	2.18	1.98	−0.20	1.90	−0.08

NOTES: TFRs for 2018 and 2023 are estimates from the 2024 revision of the WPP; TFRs for 2028 are projections under its "Medium Variant." Figures in red mark countries whose projected fertility reverses direction immediately after the estimation period.

The assumption seems unjustified to us, particularly given current trends in births and the terra incognita nature of the landscape. And while demographers at the UNPD may think they are being clear about it, very few economists are aware of the optimistic assumptions underlying these numbers.

To illustrate this optimism, Figure A2 plots the estimated (continuous line) and projected (dashed line) TFR in China and Chile according to the 2024 Revision of the WPP. Projections use the "Medium Variant." The projected recovery in both countries might occur, but nothing in the data as of today suggests it will.

Figure A2: Estimated and projected TFR in China and Chile



NOTES: Estimated and projected TFR in China and Chile according to the 2024 revision of WPP. Projections use the "Medium Variant."

B.3 Downward revisions

Next we document how successive revisions of the WPP have moved downward over time, in line with our view that its projections are systematically biased upward.

Table A4: Successive Revisions to WPP Population Projections

WPP revision	Projected population peak	Projected population in 2100 (billions)
2015	Still rising in 2100	11.213
2017	Still rising in 2100	11.184
2019	Still rising in 2100	10.875
2022	10.431 billion in 2086	10.349
2024	10.289 billion in 2084	10.180

NOTES: Projected world TFR under the "Medium Variant" of each revision of the UN's WPP.

Table A4 compiles the projected peak date and total population from successive WPP vintages. Until 2019, the WPP projected that world population would still be rising in 2100, the last year of the exercise. The 2022 revision produced, for the first time, a peak: 2086. The 2024 revision moved it earlier, to 2084. Projected population in 2100 has gone from 11.21 billion in the 2015 revision to 10.18 billion in 2024. It is worth pausing to think about how large this change is: the revision is to a stock, total population, not to a flow. Shaving a billion people off the 2100 total in nine years requires an enormous revision of the entire path of births between now and then, all in the same direction.

Table A5: Revisions to Projected World Fertility

WPP revision	Average TFR, 2025–2030	Average TFR, 2095–2100
2015	2.38	1.99
2017	2.39	1.97
2019	2.38	1.94
2022	2.29	1.84
2024	2.22	1.85

NOTES: Projected world TFR under the "Medium Variant" of each revision of the UN' WPP.

Table A5 shows a similar exercise for the average world TFR in 2025-2030 and 2095-2100, as projected from 2015 to 2024. The average world TFR for 2025-2030 has fallen from 2.38 as late as 2019 to 2.22 in the 2024 revision. For 2095-2100, over the same five years, it has fallen from 1.94 to 1.84.

The UNPD is revising its estimates and projections downward, but, from our reading, not nearly fast enough to match the data. Its numbers still overestimate births and overproject fertility, and each revision trims only a small amount from the last. As stated earlier, we place the year of peak world population circa 2056. Our reading matches the UNPD's "Low Variant" scenario much better than its "Medium Variant": the "Low Variant" puts the peak at 8.949 billion in 2053.

B.4 World TRF and the population peak

We close this Supplemental Material by stating two arguments from the main text more carefully.

First, we state that the world is already below replacement. Recall from Supplemental Material A that the world replacement rate is around 2.20. The WPP "Medium Variant" puts the world TFR in 2026 at 2.23, the consequence of 132.5 million births. So, according to the WPP, the world is still slightly above replacement.

We documented in Table A2 at least 1.6 million extra births projected for 2024 relative to what registries recorded. The divergence is likely to be larger still in 2026, especially given the birth data that arrived for Egypt, Mexico, and the Philippines in 2025, much lower than the WPP projections, probably on the order of 2.5 million. Furthermore, we suspect, though cannot prove, that the true gap is larger because of overestimates of births in Africa (recall our discussion of the Republic of Congo in Section 3). Correcting for this, we compute a world TFR in 2026 of at most 2.19, below replacement, as stated in the main text (this calculation requires details about the age structure country by country; we skip the details because, in practice, the effects of these adjustments are very minor). Notice that we are not adjusting the WPP figure drastically: we are only moving the second decimal, from 2.23 to 2.19.

In any case, we do not make too much of the exact year. One or two hundredths of a birth separate the world TFR from the replacement rate, and both numbers carry more measurement error than that. What matters is that the two series are crossing, and every source of error we can identify points the same way. Whether that happened in 2025 or happens in 2027 changes nothing in our argument. That is why the first sentence of the paper reads "humanity is likely to be below replacement level."

The main text also claims that world population will start falling around 2056, while the

"Medium Variant" of the WPP delays that fall to 2084. Our forecast rests on our reading of the fast drops in the TFR that we do not believe WPP 2024 has captured, and on our skepticism about the mean-reverting projections explained above.

Two points deserve emphasis. First, the WPP "Low Variant" puts the peak of world population in 2053 at 8.95 billion, so our are slightly less aggressive than that variant, and, given the two years of observations since WPP 2024 was released, births seem to be falling even below the Low Variant. Second, projecting the peak of a concave curve that becomes very flat near its top is notoriously difficult. Very small differences can move the peak a decade in either direction.

C Estimation details

Here we describe the details of our estimation. Recall that we want to estimate the single-factor model:

$$TFR_{i,t} = \alpha_i + \delta_i t + \beta_{i,t}\lambda_t + \epsilon_{i,t} \tag{4}$$

using least squares and assuming that $\beta_{i,t}$ is a smooth function of time.

Before estimation, we impose three normalizations on the factor. The first two normalizations, $\sum_t \lambda_t = 0$ and $\sum_t t\lambda_t = 0$, remove the level and the linear trend from the factor. In that way, λ_t represents deviations from a common trend rather than the trend itself. The third normalization, $T^{-1}\sum_t \lambda_t^2 = 1$ (where T is the sample length), fixes the scale of the factor.

These restrictions give us a convenient representation, but they do not separate $\beta_{i,t}$ from λ_t. To see this, note that, for any positive sequence c_t, the pair $(\beta_{i,t}c_t, \lambda_t/c_t)$ yields the same product. Accordingly, we estimate the decomposition under the identifying restriction that the loadings vary smoothly over time, whereas the factor is unrestricted from year to year.[30] Since this separation rests on a smoothness restriction rather than on the data alone, in the main text we focus primarily on $\beta_{i,t}\lambda_t$, the contribution of the common factor to country i's fertility rate, rather than on the loading $\beta_{i,t}$ itself.

We follow the local principal components approach of Su and Wang (2017), extending it to allow country-specific levels and linear trends. Allowing the loadings to vary over time means that we can no longer rely on the orthogonality to $(1, t)$ of country i's factor regressor, which is $\beta_i\lambda_t$ when the loading is constant but $\beta_{i,t}\lambda_t$ when it is not. The solution is to start from the constant-loading estimates $\widehat{\beta}_i$ and $\widehat{\lambda}_t$ (easily computed by least squares), and iterate on the three steps below until the maximum absolute change in the fitted values over a complete three-step cycle falls below 10^{-9} births per woman:

1. Given current values of $\widehat{\beta}_{i,t}$ and $\widehat{\lambda}_t$, we regress $TFR_{i,t} - \widehat{\beta}_{i,t}\widehat{\lambda}_t$ on a constant and a centered trend, country by country, which updates $\widehat{\alpha}_i$ and $\widehat{\delta}_i$.

[30] As an illustration of the identifying restriction, let $u_t = (t-1)/T$ for $t = 1, \ldots, T$. We hold the transformed loading paths $\beta_{i,t}c_t$ fixed, up to the global rescaling implied by the factor normalization, and re-optimize all the remaining parameters. Doing so raises the sum of squared residuals by 18% for $c_t = 1 + u_t$ and by 27% for $c_t = 1 + 0.6\sin(2\pi u_t)$, while the corresponding factors, after sign alignment, still correlate 0.98 and 0.96 with our estimate. Separately, initializing the unrestricted iteration from either transformed pair returns the baseline estimates.

2. Given $\widehat{\lambda}_t$, we estimate $\widehat{\beta}_{i,t}$ by kernel-weighted least squares of the detrended data on $\widehat{\lambda}$, using an Epanechnikov kernel with bandwidth $h = 20$ years. At interior dates, this gives positive weight to observations fewer than twenty years away from t on either side.

3. Given the loadings, we recover $\widehat{\lambda}_t$ from the cross section and impose the normalizations, projecting onto the orthogonal complement of $\{1, t\}$ under the weights $\sum_i \widehat{\beta}_{i,t}^2$. Then, we rescale and fix the sign, requiring the country with the largest average loading to load positively. We need the weights $\sum_i \widehat{\beta}_{i,t}^2$ because the unweighted projection is not the constrained minimizer, since the precision with which λ_t is estimated varies over the sample.

We check that the results are robust across a grid of bandwidths from ten years to the full sample, and we also compare them with the constant-loading model. We avoid selecting the bandwidth by leave-one-year-out cross-validation of the loading step, conditional on the estimated factor and trends, because the idiosyncratic components are highly persistent. In our application, this criterion selects the smallest bandwidth in the grid. When we instead leave temporal gaps of eight years or more between the omitted observations and the estimation sample, the selected bandwidth increases substantially, consistent with the view that the preference for very small bandwidths is driven by short-run persistence rather than by the long-run evolution of the loadings.

We compute standard errors using a moving-block residual bootstrap (Künsch, 1989, Horowitz, 2019). The idiosyncratic components are strongly serially correlated, so we recenter the residuals country by country and resample the residual matrix in contiguous blocks of eight years. The same time blocks are resampled for all countries. Adding the resampled residuals to the fitted values gives us a synthetic panel; we draw 5,000 such panels and re-estimate the model on each. Standard errors are computed from bootstrap replications for which the maximum absolute change in the fitted values over a complete three-step cycle falls below 10^{-9}, the same tolerance used for the baseline estimate, without reaching the iteration cap. In our application, all 5,000 bootstrap replications satisfied this criterion, so no replications were discarded. Also, we warm-start each replication at the point estimate and, after re-estimation, align the sign of the bootstrap factor with that of $\widehat{\lambda}$. Because both country-specific trends and local loadings are estimated with substantial sampling uncertainty, individual-country estimates remain noisy.

Our estimates suffer from two weaknesses. First, $\widehat{\beta}_{i,t}$ is identified only where $\widehat{\lambda}_t$ carries sufficient local information, measured by the denominator of the kernel regression, $\sum_s K_h(t,s)\widehat{\lambda}_s^2$. Since this quantity falls by roughly a factor of seven between the 1970s and the 2020s, $\widehat{\beta}_{i,t}$ grows large in the later years to compensate. This is also why we spend more space in the main text discussing $\widehat{\beta}_{i,t}\widehat{\lambda}_t$, which is invariant to how scale is divided between the loading and the factor.

Second, allowing the loading to vary over time weakens the separation between the linear trend and the common component, since a sufficiently smooth loading can absorb part of a country's long-run evolution. In line with this interpretation, our $\widehat{\delta}_i$ correlate 0.88 with their constant-loading counterparts, while their mean changes from -0.049 to -0.062 births per woman per year.

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