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# Heritable Fertility is Not Sufficient for Long-Term Population Growth

**Abstract:** All leading long-term global population projections agree on continuing fertility decline, resulting in a rate of population size growth that will continue to decline towards zero and would eventually turn negative. However, a literature inspired by mathematical biology has suggested that because fertility is heritable (*i.e.*, higher-fertility parents tend to have higher-fertility children) and heterogeneous within a population, long-term population growth must eventually be positive. In this research note, we show that heritable fertility is not sufficient for positive long-term population growth, for empirical and theoretical reasons. First, empirically, even higher-fertility sub-populations show declining fertility rates which may eventually be below replacement (and in some populations already are). Second, in a simple Markov model, because heritability is imperfect, the combination of heritability and fertility rates may be quantitatively insufficient: it may be that higher-fertility parents nevertheless produce too few children who retain higher-fertility preferences. These results underscore the importance both of understanding the possible consequences of long-term fertility decline and depopulation and of the causal importance of culture and choice in human populations.

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**Abstract**

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## Introduction

All leading long-term global population projections agree on projecting continued fertility decline. Fertility worldwide is projected to fall below replacement levels, which would eventually cause negative global population growth (KC and Lutz, 2017; United Nations, Department of Economic and Social Affairs, Population Division, 2019; Vollset et al., 2020). Survey evidence confirms wide agreement among demographic experts that fertility will continue to fall (Gietel-Basten et al., 2014). However, a set of recent publications that apply models of heritability from the mathematical biology literature propose that low fertility is unlikely to endure and global population growth is unlikely to become negative (Collins and Page, 2019; Burger and DeLong, 2016; Murphy and Wang, 2003; Ellis et al., 2017); these arguments also appear in popular-audience accounts of fertility (Kaufmann, 2010; Ingraham, 2015).[1] Such authors reason that high fertility is heritable, and so, if there are higher and lower fertility patterns exhibited within sub-populations, eventually the composition of the population will converge towards the higher-fertility pattern.[2]

In this research note, we observe that this mathematical fact is not sufficient for positive long-term population growth (PLTPG).[3] One reason is that researchers should not conflate *higher* fertility within a heterogeneous population with *high* or *above-replacement* fertility: it is an empirical question whether future higher-fertility sub-populations will have above replacement fertility. If not, then population growth will be negative. We show that there is strong historical and global evidence that even higher-fertility groups will eventually trend to near or below replacement fertility. Beyond this, the existence of a sub-population with above-replacement fertility is not sufficient for PLTPG, even with fertility heritability. This is because it might be that an insufficient number of children of high-fertility parents retain their parents' behaviors—that is, even if fertility is highly correlated within a family across generations, the correlation may be less than 1.0. We formalize the conditions under which heritable fertility leads to PLTPG in a stylized Markov model that builds upon the models to which we respond, especially Kolk et al. (2014): if enough children of high-fertility parents become low-fertility adults, long-term population growth can be negative even with both strong heritability and an above-replacement-fertility sub-population.

[1] Indeed, we were motivated to write this paper because a research funder explained to us that this argument influences their allocative decisions.

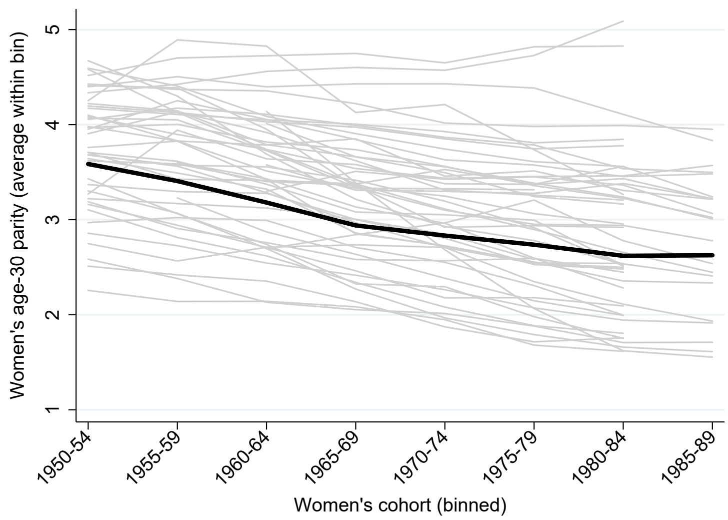
[2] In fact, the model of Collins and Page (2019), representative of this broader literature, implies the stronger claim that aggregate fertility rates are *always* increasing via this mechanism in post- demographic transition settings, counter to the experiences of developed countries over the previous half-century.

[3] Our research note complements the empirical findings of Vogl (2020), who does not focus on long-term population growth, but quantifies with survey data that any heritability effect on aggregate fertility has historically been small.

In the remainder of this research note, we briefly present these two facts. In the next section, we review empirical evidence that even higher-fertility populations and sub-populations are converging towards near- or below-replacement fertility. In the following section, we use a parsimonious theoretical model of fertility heritability to show that heritability is not sufficient for PLTPG, especially in the likely empirical case that higher-fertility sub-populations have near-replacement fertility rates.

## Evidence of fertility decline among high fertility groups

Figure 1: Fertility decline is found in diverse populations: DHS



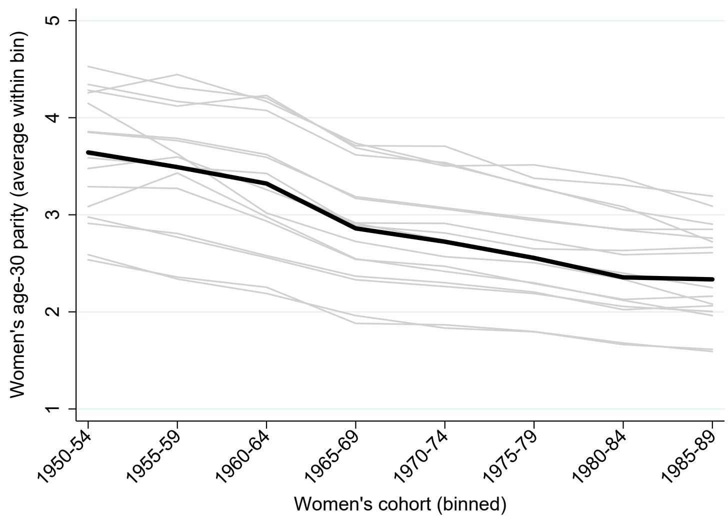

*Note:* This figure shows women's age-30 parity by birth cohort for 48 different countries. Data are taken from the Demographic and Health Surveys. The horizontal axis is cohort (year of birth) binned into five-year increments from 1950 to 1989; the vertical axis is the average parity at age 30 of women in that cohort bin. Each gray line represents a different country, and the black line represents the average across countries.

Figure 1 documents fertility trends in 48 different countries using data from the Demographic and Health Survey (DHS).[4] These 48 countries comprise nearly 45 percent of the world's population and 60 percent of births each year. These countries are primarily developing and emerging economies, which is useful for our purposes because these are, in general, the populations for which above-replacement fertility currently exists. In Figure 1, the horizontal axis is cohort (year of birth) binned into five-year increments from 1950 to 1989; the vertical axis is the average parity at age 30 of women

[4]The set of 48 countries is the subset of all DHS countries for which at least 500 women are interviewed in at least 6 of the 8 cohort bins pictured.

in that cohort bin.[5] Each gray line represents a different country, and the black line represents the average across countries. All but two of the 48 countries have decreasing fertility rates. The evidence offers no reason to conclude that the downward trend will stop above replacement levels. Indeed, many of even these emerging and developing economies are already below or near replacement level.

Figure 2: Fertility decline is found in diverse sub-populations: India




*Note:* This figure shows women's age-30 parity by cohort for 16 different sub-populations in India. The 16 non-overlapping groups are generated by interacting indicators for: north-India/south-India, rural/urban, Muslim/not-Muslim, and no-education/some-education. Data are taken from the Demographic and Health Survey. The horizontal axis of this figure is cohort (year of birth) binned into five-year increments from 1950 to 1989; the vertical axis is the average parity at age 30 of women in that cohort bin. Each gray line represents a different sub-population, and the black line represents the average for India overall.

Figure 2 focuses on India, which accounts for one-sixth of the world's population and has historically be a focus of global population policy debates (Connelly, 2010). India is home to diverse sub-populations, who differ, among other ways, in their average fertility levels. In Figure 2, we categorize women in India in the DHS into 16 non-overlapping groups by interacting indicators for: south-India/other-states, rural/urban, Muslim/not-Muslim, and no-education/some-education. For example, one of the gray lines represents South-Indian, rural, Muslim women with some education. The axes are as before: cohort and fertility, respectively. Each of the 16 groups demonstrates a clear downward slope. That is, as with nearly all countries in the DHS, all major sub-populations within India, including those with the highest levels of fertility, have declining fertility. These em-

[5]In principle, such cohort fertility rates could be declining over time merely because women are delaying fertility to later ages; however, the declining trends documented in this section also appear for later-age cohort fertility, but the data would be necessarily truncated to earlier cohorts.

pirical facts cast doubt on a necessary condition for PLTPG: that *higher*-fertility sub-populations will sustain *high* (that is, above replacement) levels of fertility.

Figures 1 and 2 focus on developing countries, where fertility is generally highest today. But discussions of heritability in fertility are often motivated by reference to higher fertility among religious sub-populations in developed countries, such as the United States (Kaufmann, 2010; Ingraham, 2015; Ellis et al., 2017). Although these observations are not essential to our argument, we note two important facts about demographic patterns in the United States. First, fertility rates among religious Americans, despite a consistently higher level than among non-religious Americans, are falling approximately in parallel to fertility rates for the whole population (Perry and Schleifer, 2019). For example, the National Survey of Family Growth (NSFG) shows that, between cohorts born in the 1940s and cohorts born in the 1970s, completed fertility for both religious and non-religious women fell by approximately 20 percent.[6] Second, heritability of such group identities—whether defined by religion, educational attainment, rural/urban status, or cultural conservatism—are not transmitted perfectly across generations. The NSFG shows that the fraction of Americans who report being religious is falling over time, from 57 percent in 1988 to 43 percent in 2019. We take up the implications of such imperfect intergenerational transmission next.

## A stylized Markov model of population dynamics

So far we have noted that the empirical evidence suggests that a diverse set of sub-groups are trending towards below-replacement fertility. However, some authors have argued that if even one sub-group remains above replacement, then this high-fertility group grows its population share over many generations, becoming the dominant share and driving population TFR towards that sub-group's TFR (Collins and Page, 2019). In this section, we show analytically that the existence of such a sub-group is not a sufficient condition for PLTPG. Instead, we demonstrate in a two-type model that, under realistic conditions, long-run population decline can exist in a world with a sub-group that has both above-replacement fertility and heritable fertility. The intuition, formalized in our model is this: If high-fertility types have offspring at above-replacement levels, but only some fraction of those offspring inherit the high-fertility type, then the size of the high fertility group (and the overall population) can nonetheless decline. Our model highlights the conditions that determine

[6] "Religious" is defined as attending religious services at least once per month.

positive versus negative population growth in a heritability framework.

Define high- and low-fertility types $i \in \{H, L\}$ with reproductive rates $F_H > 1 > F_L$, respectively, where we have simplified to a single-sex environment such that a reproductive rate 1 is replacement level. This two-type model with transmissible fertility from parents to offspring builds on the structure employed by Kolk et al. (2014), but adds the feature that the inherited fertility type, which is a function solely of the parent's type, is imperfectly transmitted. In particular, the offspring of type $i$ retain their parent's fertility preferences with probability $p_{i \to i}$ and switch types with probability $(1 - p_{i \to i})$. Notice that there are no time subscripts on any the model's fertility rate parameters ($F_i$); the setting is one of post-demographic transition where we have assumed socioeconomic factors have settled to long-run averages—for example, the assumption implies that TFR of American religious conservatives has ceased its decline and stabilized. The question of interest is what must be true of a post-transition world to generate PLTPG.

In this setting the evolution of types can be written as follows, where $N_i$ is the number of types in each period.

$$\mathbf{N}_{t+1} = \mathbf{A}\mathbf{N}_t \tag{1}$$

where:

$$\mathbf{N} = \begin{bmatrix} N_H \\ N_L \end{bmatrix} \qquad \mathbf{A} = \begin{bmatrix} p_{H \to H} F_H & (1 - p_{L \to L}) F_L \\ (1 - p_{H \to H}) F_H & p_{L \to L} F_L \end{bmatrix},$$

and the Markov transition matrix $\mathbf{A}$ specifies how types evolve. The number of high types at $t + 1$ equals $N_{H,t}(p_{H \to H} F_H) + N_{L,t}((1 - p_{L \to L}) F_L)$, which could be greater or less than the number of high types at $t$, depending on model parameters. Because, by construction, the low-types cannot sustain their numbers without inflow ($F_L < 1$), it is straightforward to show that there is PLTPG if and only if there is long-run growth in the subset of high-types.[7]

To focus on the long-run tendency of high-types, then, assume that $p_{L \to L} = 1$. That is, children of low types inherit that type with certainty. This stylizes the empirical fact that nearly all high-fertility groups—the religious, the rural, the less-educated, the less-cosmopolitan—have much more outflow than inflow. This exact assumption is not necessary for the model's main qualitative conclusions,

[7] In the case where high-types grow, temporary population decline is possible if the low-types shrink sufficiently fast at the start; eventually, however, only high-types are left and their population growth necessarily takes over.

but it simplifies exposition. Combining this one-way switching assumption with the general property of Markov processes that $\mathbf{N}_t = \mathbf{A}^t\mathbf{N}_0$, it can be shown that the population of high-types evolves according to $N_{H,t} = (p_{H\to H} \times F_H)^t N_{H,0}$. The high-types increase—and therefore the long-run aggregate population increases—if and only if

$$p_{H\to H} \times F_H > 1.$$

This condition is the essential one.

What does $p_{H\to H} \times F_H > 1$ mean in practice? Take the example of high-religiosity Americans. This group has an above-replacement TFR (high $F_H$ in our model) but has seen significant outflow of their offspring towards secular, low-fertility lifestyles (low $p_{H\to H}$ in our model). As a result, the share of the population with this characteristic is shrinking, despite their above-replacement fertility. There is no reason then to anticipate that this subgroup will come to dominate the aggregate.

Note that if this model were the true data generating process in some population, then a regression of sibsize (parent's fertility) on own-fertility in that population would return a positive coefficient. Thus, the model could produce exactly the type of empirical correlations pointed to (incorrectly) as evidence that heritable fertility among high fertility groups implies long-term population growth. This is true despite the fact that this model produces long-term population decline. This is the key error in this literature: the existence of (high, positive) mother-daughter fertility correlations and a higher-fertility subgroup are not enough to infer whether population-level cohort fertility rates should be expected to increase over time.

Finally, to return to the point of our empirical section, $F_H$ may itself decline over time below replacement, which would ensure that $F_H \times p_{H\to H} < 1$. Especially as fertility rates become low, fertility outcomes are importantly shaped by fertility preferences, choices, and intentions (*e.g.* Pritchett, 1994; Goldstein et al., 2003; Gietel-Basten, 2019; Yeatman et al., 2020). One key way in which human population dynamics differ from the mathematical dynamics of non-human populations is the importance of fertility determinants such as culture, economics, preferences, and contraception (Kohler and Rodgers, 2003). Social, cultural, and economic determinants of fertility preferences could change, especially over the long run. However, if future humans desire and are able to achieve below-replacement fertility, then heritability of fertility preferences within a heterogeneous population will be compatible with enduring negative long-term population growth.

## Discussion

Leading population projections suggest there is a substantial probability that global population growth will become zero or negative moving into the next century. Depopulation, if it occurs, may have many consequences for societies and economies (Morgan, 2003; Jones, 2020). Here we respond to a literature motivated by mathematical biology that intends to cast doubt on such demographic projections. But human fertility is unlike other animals because it is shaped by culture, economics, and intention. Building on the work of Kolk et al. (2014), we have shown here that fertility heritability is not sufficient to prevent long-run population decline.

To generate PLTPG from the simple model above, the number of children that retain the high fertility preferences of their parents must exceed replacement level; it is not sufficient merely that higher-fertility types have above-replacement fertility, even with heritability. The condition for PLTPG is met through some combination of *both* high fertility rates and low cultural outflow. The empirical evidence above suggests that the "higher-fertility" types of the future may have rates near (or even below) replacement level, leaving little (or no) room to be consistent with PLTPG in the presence of any cultural outflow.

While there may yet arise population subsets with sufficiently low intergenerational outflow to meet this condition, evidence broadly suggests that most socio-economic traits have quantitatively insufficient intergenerational correlation. To name just a few, religious practice, political affiliation, and incomes have quantitatively less intergenerational correlation than would be required (Vogl and Freese, 2020; Chetty et al., 2014). Fertility itself has been recently examined in the post-demographic-transition world and has likewise been shown to have positive but low intergenerational correlation, providing evidence that the persistence parameter above, $p_{H \to H}$, is likely low (Vogl, 2020).

The 20th century was characterized by uniquely rapid population growth (Lam, 2011). Understanding the implications of a regime switch to one of population decline, or even merely stabilization, is of clear importance. Contrary to some arguments in the literature, empirical facts and models of heritability do not provide reason to conclude that positive population growth is bound to continue via the dynamics of a higher-fertility type making up an ever-increasing share of the global population.

## References


Burger, Oskar and John P DeLong (2016) "What if fertility decline is not permanent? The need for an evolutionarily informed approach to understanding low fertility," *Philosophical Transactions of the Royal Society B: Biological Sciences*, 371 (1692), 20150157.

Chetty, Raj, Nathaniel Hendren, Patrick Kline, and Emmanuel Saez (2014) "Where is the land of Opportunity? The Geography of Intergenerational Mobility in the United States," *The Quarterly Journal of Economics*, 129 (4), 1553–1623.

Collins, Jason and Lionel Page (2019) "The heritability of fertility makes world population stabilization unlikely in the foreseeable future," *Evolution and Human Behavior*, 40 (1), 105–111, `https://www.sciencedirect.com/science/article/pii/S1090513817302799`.

Connelly, Matthew (2010) *Fatal misconception: The struggle to control world population*: Harvard University Press.

Ellis, Lee, Anthony W Hoskin, Edward Dutton, and Helmuth Nyborg (2017) "The future of secularism: A biologically informed theory supplemented with cross-cultural evidence," *Evolutionary Psychological Science*, 3 (3), 224–242.

Gietel-Basten, Stuart (2019) *The "Population Problem" in Pacific Asia*: Oxford University Press.

Gietel-Basten, Stuart, Tomáš Sobotka, Kryštof Zeman et al. (2014) "Future fertility in low fertility countries," in *World Population and Human Capital in the Twenty-First Century: An Overview*: Oxford.

Goldstein, Joshua, Wolfgang Lutz, and Maria Rita Testa (2003) "The emergence of sub-replacement family size ideals in Europe," *Population research and policy review*, 22 (5), 479–496.

Ingraham, Christopher (2015) "Charted: The religions that make the most babies," *The Washington Post*.

Jones, Charles I (2020) "The End of Economic Growth? Unintended Consequences of a Declining Population," Working Paper 26651, National Bureau of Economic Research, `http://www.nber.org/papers/w26651`.

Kaufmann, Eric (2010) *Shall the religious inherit the earth?: Demography and politics in the twenty-first century*: Profile Books.

KC, Samir and Wolfgang Lutz (2017) "The human core of the shared socioeconomic pathways: Population scenarios by age, sex and level of education for all countries to 2100," *Global Environmental Change*, 42, 181–192, `https://www.sciencedirect.com/science/article/pii/S0959378014001095`.

Kohler, Hans-Peter and Joseph L Rodgers (2003) "Education, fertility and heritability: Explaining a paradox," *Offspring: Human fertility behavior in biodemographic perspective*, 46–90.

Kolk, Martin, Daniel Cownden, and Magnus Enquist (2014) "Correlations in fertility across generations: can low fertility persist?" *Proceedings of the Royal Society B: Biological Sciences*, 281 (1779), 20132561.

Lam, David (2011) "How the world survived the population bomb: Lessons from 50 years of extraordinary demographic history," *Demography*, 48 (4), 1231–1262.

Morgan, S Philip (2003) "Is low fertility a twenty-first-century demographic crisis?" *Demography*, 40 (4), 589–603.

Murphy, Mike and Duolao Wang (2003) "The impact of intergenerationally-transmitted fertility and nuptiality on population dynamics in contemporary populations," in *The biodemography of human reproduction and fertility*, 209–228: Springer.

Perry, Samuel L and Cyrus Schleifer (2019) "Are the faithful becoming less fruitful? The decline of conservative Protestant fertility and the growing importance of religious practice and belief in childbearing in the US," *Social Science Research*, 78, 137–155.

Pritchett, Lant H (1994) "Desired Fertility and the Impact of Population Policies," *Population and Development Review*, 1–55.

United Nations, Department of Economic and Social Affairs, Population Division (2019) *World population prospects 2019; Highlights*: United Nations.

Vogl, Tom S (2020) "Intergenerational associations and the fertility transition," *Journal of the European Economic Association*, 18 (6), 2972–3005.

Vogl, Tom S. and Jeremy Freese (2020) "Differential fertility makes society more conservative on family values," *Proceedings of the National Academy of Sciences*, 117 (14), 7696–7701, `https://www.pnas.org/content/117/14/7696`.

Vollset, Stein Emil et al. (2020) "Fertility, mortality, migration, and population scenarios for 195 countries and territories from 2017 to 2100: a forecasting analysis for the Global Burden of Disease Study," *The Lancet*, 396 (10258), 1285–1306, `https://doi.org/10.1016/S0140-6736(20)30677-2`.

Yeatman, Sara, Jenny Trinitapoli, and Sarah Garver (2020) "The enduring case for fertility desires," *Demography*, 57 (6), 2047–2056.