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Does Fertility or Mortality Drive Contemporary Population Aging? The Revisionist View Revisited

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ABSTRACT: “Does Fertility or Mortality Drive Contemporary Population Aging? The Revisionist View Revisited”

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Why are contemporary populations still aging? In the Classic view population aging has been driven almost entirely by fertility decline over the demographic transition, while mortality decline has played a minor role. In this view, populations today are still aging because they are still converging toward the new older stable age distribution. But in the past 25 years an elegant mathematical decomposition of changing mean ages has sometimes been interpreted as showing that recent aging is mainly due to declining mortality rather than fertility. Here we question this interpretation, and argue that it is important to evaluate the indirect effects of mortality change as well as the direct ones. We suggest that the gold standard for this problem is the analytic simulation with explicit counterfactual comparisons. Analytic simulations show that fertility decline is largely responsible for the old age of contemporary populations, and has by far the largest role in accounting for continuing aging from 2005-2010. We further analyze the key equation for the growth rate by age to reveal (at least partially) the indirect effect of mortality decline on the series of births, showing formally the source of the conflicting conclusions.

Introduction

Why are populations of rich countries now so much older than they were a 100 or 200 years ago? Comparative stable population analysis provides an answer: they are old now mainly because their fertility has declined, and to a much smaller degree because mortality is lower. This is the Classic view (Coale, 1956, 1957; Keyfitz, 1975), illustrated in Figure 1 of Lee (2011) which shows isoquants of the Old Age Dependency Ratio (OADR) for different levels of fertility and life expectancy. Figure 1, the isoquant map for the OADR illustrates this point. Movements from left to right on this graph go from low to high life expectancy, and have little effect on the OADR until reaching levels of 70 years. By contrast vertical movement from high to low fertility, cross many OADR contours indicating a strong effect on population aging.

To give a concrete example, European TFR was around 5 births per woman and life expectancy at birth was around 35 years in the mid-19th century (exact values don't matter much here), and stable population models tell us that the old age dependency ratio (OADR= Pop(65+)/Pop(20-64)) would have been around .08. With its current TFR of 1.6 (which has not changed much in the past thirty years) but an unchanged life expectancy of 35, the stable old age dependency ratio would be .28, 3.5 times as high. But if we reverse the experiment and keep the TFR at 5 while letting life expectancy rise to 78, the stable population OADR would be only about .11, an increase of .03, about a sixth as large as the increase due to fertility decline. With low values of both fertility and mortality the stable OADR would be .40, greater than .31, the sum of the separate effects of fertility and mortality, because the two interact. So the demographic origin of old populations relative to the past is mainly low fertility.

However, comparative stable population analysis tells us nothing about the period of transition from one stable population to another, and both the more developed countries (MDCs) and the less developed countries (LDCs) are currently in this sort of transitional situation. Real populations are not stable, and in fact are still aging. A series of papers over the past 25 years (Horiuchi and Preston, 1988; Preston, Himes and Eggers, 1989; Horiuchi, 1991; Casseli and Vallin, 1993; and most recently Preston and Stokes, 2012) have argued that the continuing aging in recent years is mainly due to mortality decline.[i] This line of research has developed an elegant mathematical decomposition of changes in the mean age of the population, and carried out many related analyses that help us understand transitional changes in population age distributions. However, we suggest that this literature appears to have taken a wrong turn when it concluded that recent population aging is mainly due to mortality decline rather than fertility decline, according a much more important role to continuing mortality decline than seems consistent with the stable population comparison. For example, "…the ageing of female population in Japan in the recent past is mainly due to the decline of mortality…." (Horiuchi, 1991, p.46) and "In MDCs, mortality improvements are entirely responsible for the observed increase in the proportion of the population at older ages." (Preston and Stokes, 2012:230); and "While trends in numbers of births (see table 7) contribute to a great extent to this spectacular increase in population ageing, the role played by mortality trends is even more significant." (Vallin and Casseli, 1990, p.23, in reference to France and Italy). How can these conclusions be so different than those suggested by the stable population analysis or the analytic projections of Coale (1957)?

One possible explanation is that fertility decline was important in the past for making populations old, but that this effect has now been used up, so that further aging is due to mortality decline. Horiuchi (1991) sets out this argument clearly. This explanation certainly seems possible, because as Horiuchi points out, as mortality continues to decline its effects are increasingly concentrated at older ages, while fertility decline is limited in extent. But how would we know if the effect of past fertility decline were finished? We will consider this possibility, but reject it.

Preston and Stokes state explicitly, "The answer supplied by this accounting approach is not necessarily the same as what would be supplied by models or by counterfactual simulations. In particular, any indirect effect of mortality change on the annual number of births is included in the $r_B(x)$ series, rather than in the mortality series per se. Such an effect of mortality decline on births would be rejuvenating and would offset some of the aging effect resulting from inter-cohort improvements in survivorship." But without taking account of these indirect effects, how can one say anything about the relative roles of mortality and fertility in causing population aging? How do we know that the rejuvenating effect of declining mortality would offset only "some" of the aging effect and not all of it, or would not completely reverse the direction of the effect?

Based on this literature, the view is now widespread that mortality decline rather than fertility decline is principally responsible for current population aging. We argue here that this view is mistaken, and that the principal responsibility still lies with fertility. In the remainder of the paper we will first discuss further the revisionist view. Next we will present some analytic simulations that highlight the roles of changing fertility and mortality in population aging in India and MDCs. After that we will present further mathematical analysis of the basic model, and we will conclude with a numerical evaluation of the effects of fertility and mortality change, based on that analysis (this last step is not yet included in the paper).

The Revisionist View and Some Hypothetical Cases

Consider the following artificial scenario. A closed population initially has high fertility and high mortality and a stable age distribution with slow population growth and a young population age distribution. Suddenly fertility drops from six births per woman to 1.5 births per woman (TFR) while life expectancy at birth increases from 40 to 70 years, with fertility and mortality remaining constant thereafter. This population will immediately begin to experience population aging, a process that will continue for many decades as the population age distribution converges slowly to the new stable distribution which will be very old. Yet by assumption, there are no changes in fertility or mortality after the initial declines, whereas the population continues to age for many decades. The analytic machinery of the revisionist approach applied to this ongoing population aging would allocate no responsibility to mortality.

The difficulty is that the process of adjustment to the new levels of fertility and mortality is not explicitly acknowledged in the method. This adjustment process enters in through the pattern of changes in the numbers of births, and this key feature of the age transition is not further analyzed. It is easy to think that changes in the number of births reflect changes in fertility. Of course, to some degree this is true. But it is also true that declining mortality tends to raise the population growth rate and drive up the number of births. In the developing country examples presented, this rate of change of births stays fairly close to zero, or perhaps is negative as in the case of China from 1950 to 2010. Yet the Chinese population is 2.4 times as large in 2010 as in 1950. The reason that the annual number of births declines over this period is that fertility drops from 6.11 to 1.64 (UN, 2011). If instead fertility had remained at 6.11 births per woman while life expectancy rose from 45 to 72, the population growth rate and the growth in the number of births would have been enormous, and the population in 2010 would have been very young. Instead the birth series was the dog that did not bark. The reason it did not bark is that the effect of the fertility decline offset the effect of the mortality decline. The decline in fertility is the primary reason why the population is aging as the population converges toward the stable population age distribution. Without the fertility decline, the rapid mortality decline would have created a very young population.

Fertility does not enter at all into either the empirical analysis or the accounting framework. Instead, what enters is births and the rate of growth of the number of births. This rate of growth, if decomposed (as we will do later, at least partially), would be seen to depend on mortality, fertility, migration and the inherited population age distribution. Declining mortality will tend to speed up the growth rate of births, offsetting the effects of declining fertility, as is explained in the passage from Preston and Stokes that is quoted above.

Analytic Simulations for India and MDCs

Analytic simulations can be used to generate counterfactual outcomes. What is the appropriate counterfactual? Because the analytic framework used is based on cohort histories, we need to go back a century or so to simulate age distributions. We will contrast counterfactuals with constant fertility and variable mortality to those with constant mortality and variable fertility. For simplicity we will abstract from migration and create populations that are closed by construction but are based on the historical fertility and mortality of India and the MDCs. The data generated through these simulations can then be analyzed.

The focus in the Preston-Stokes paper is on the change in the mean age of the population between 2005 and 2010. Table 1 shows this change for India derived from three different analytic simulations: First, the baseline, which uses the actual history of both fertility and mortality; second, varying mortality and constant fertility; and third, varying fertility and constant mortality. Other columns of the tables show similar results for other measures of population aging, % at age 65 or above, and the Old Age Dependency Ratio (OADR) here defined as the ratio of those 65 and over to those age 20 to 64.

We see in Table 1 that there was a one year increase in the mean age of the population between 2005 and 2010. If we counterfactually hold fertility constant and let mortality follow its historic trajectory, the mean age of the population actually declines by .1 year rather than rising. The other counterfactual, in which mortality is constant and fertility varies, shows a one year increase in the mean age, very similar to the baseline population simulation. Results for the other two measures of aging likewise show that the fertility decline is responsible for most of the population aging over this five year period.

Table 2 is structured in exactly the same way, but reports results for MDCs. The mean age of the baseline population increased by .82 years between 2005 and 2010. The simulation that held fertility constant and let mortality vary produced an increase of .12 years in the mean age, while the counterfactual with constant mortality and varying fertility produced an increase of .62 years, five times as great. For the other two aging measures, fertility explained about two and a half times as much aging as did mortality.

Why are these results so different than those in Horiuchi (1991), Casseli-Vallin (1990), or Preston-Stokes (2012)? The differences arise from the indirect effect of mortality decline on the growth rate, which we can also illustrate drawing on the counterfactual simulations. Figure 2 shows the growth rate of the number of births for the three simulations for India. The red line show the annual growth rate of births on the counterfactual assumption that fertility remained constant at its level in 1900 while mortality followed its actual trajectory from 1900 to 2010. This line rises strongly over the 110 years, showing that the growth rate of the number of the annual number of births strongly accelerated, making more recent generations relatively larger at birth, and therefore tending to make the population younger. This consequence of declining mortality occurs because more births are surviving to reproductive age, boosting population growth rates. This more than offsets the direct effect on the age distribution of the increase in proportions surviving from birth to each age, so that the net effect of mortality decline has been to make the population younger.

The green line shows the counterfactual in which mortality is held constant at its level in 1900 while fertility follows its actual trajectory decline from 1900 to 2010. We see that as fertility began its decline after mid-century, the growth rate of number of births turned increasingly negative, dropping to about minus 3% per year for the last ten years. This decline in the growth rate of births means that recently born generations are relatively smaller at birth, such that the growth rate of births when current old people were born was about 3% higher. This declining growth rate of births makes the population older, working in the opposite direction to the decline in mortality.

The corresponding results for MDCs are shown in Figure 3, and are far less dramatic. Nonetheless, we see that with varying mortality the rate of growth of births rises somewhat from left to right whereas with varying fertility it declines. A falling growth rate of births raises the mean age of the population, and a rising one reduces the mean age.

Figure 4 shows the counterfactual simulations and baseline for the mean age of the population in India. The mean age column in Table 1 is based on the change between the last two points of these plots. The constant mortality and varying fertility counterfactual tracks the main changes in the baseline mean age fairly well, while the varying mortality simulation heads downwards in the wrong direction starting around mid-century.

Figure 5 shows the corresponding results for MDCs. In this case the varying fertility counterfactual tracks the baseline mean age amazingly well, while the varying mortality counterfactual remains flat.

Plots of the other two measures of population aging do not show such close matches by the counterfactual with varying fertility and constant mortality.

Analysis of the Basic Equation

Preston and Stokes (2012), henceforth PS, derive the following result, here expressed in continuous notation:

(1.1) $$r(x,t) = r_B(x,t) + d\left[\ln p(x,t-x)\right]/dt + d\left[\ln j(x,t-x)\right]/dt$$

On the left is the rate of growth of the population at age x in time t (not longitudinally, but as the population at given age x changes with time), which is equal to the sum of three terms: the rate of change of births x years before t, plus the rate of change of the proportion surviving from birth x years ago to age x at time t, plus the rate of change in the factor by which the number of immigrants altered the size of the birth cohort age x at time t.

We believe that analysts working within this framework have focused on the second term on the right, representing the change in cohort survival. This seems to be the natural expression of the role of mortality change. The first term on the right, the rate of growth of the number of births x years before t, has received less attention, and is sometimes referred to as the “birth rate” which leads to confusion with fertility. In fact, this term $r_B(x,t)$ depends on the population age distribution at time *t-x*, on the rate of change of the effect of earlier mortality on the survival of female births to time *t-x*, and on the rate of change of fertility at time *t-x*. Fertility is only one of these three influences, and may not be the most important one. Below, we will make a start on showing this analytically.

To simplify, we will ignore the last term, expressing the effect of migration, and focus on the role of survival and number of births. In particular, we are interested in the effect of changing mortality and fertility on the changing number of births, and also on the effect of changes in the base population and its age distribution. We will also simplify by assuming that age specific fertility at age x and time t, call it m(x,t), can be written as the product of a fixed age distribution function f(x) that integrates to 1.0, and the TFR at time t, call it F(t), so that m(x,t) = F(t)f(x). To explore these effects, we begin with an expression for the number of births in year t in a closed population, where α and β are the lower and upper age limits for childbearing. We can think of this as applying to the whole population if take mortality to be equal by sex and the sex ratio at birth to be .5, or we can let F be the GRR and take this equation to refer to the female population:

(1.2) $$B(t) = \int_\alpha^\beta B(t-x) m(x,t)\, p(x,t-x)\, dx$$

Substituting in F(t)f(x,t) for m(x,t) we find:

(1.3) $$B(t) = F(t)\int_\alpha^\beta B(t-x) f(x)\, p(x,t-x)\, dx$$

To find the rate of change of this expression we differentiate the natural log of both sides with respect to time to get:

(1.4) $$\frac{d\ln\left[B(t)\right]}{dt} = \frac{d\ln\left[F(t)\right]}{dt} + \frac{F(t)}{B(t)}\int_\alpha^\beta \frac{dB(t-x)}{dt} f(x)\, p(x,t-x)\, dx + \frac{F(t)}{B(t)}\int_\alpha^\beta B(t-x) f(x) \frac{dp(x,t-x)}{dt} dx$$

From this we see that the proportional rate of change in the number of births at time t, $r_B\left(t\right)$, is the sum of three terms. The first is the proportional rate of change of the TFR at time t. The second term is an integral expressing the effect on current births of changes in the number of past births. This could be considered the "inertia" effect. It is the influence of the historical population age distribution, independent of subsequent changes in fertility and mortality between time t-α and t, but reflecting the effects of earlier variation in fertility and mortality before time t-α. The third term reflects the influence of changes in the proportion surviving from birth to age x.

However, because we take B(s) as given for many years this is not a full decomposition. It is a partial decomposition. For a full decomposition we would have to go back to the beginning of time, and view the time series of births and all subsequent population age distributions as deriving entirely from the trajectories of age specific fertility and mortality (or those plus migration). The current decomposition is complete only for the past 30 years (twice α) although it might be reasonably accurate for another 10 years back if fertility below age 20 is low. A more complete decomposition could be carried out over more multiples of α. For the more developed countries of Europe we would have to go back to the late 19th century before fertility began to decline. Even then we would be missing the earlier inception of mortality decline. In practice, analytic simulations starting 100 years ago offer the most practical approach.

Each of these three sources of change can, in principle, be evaluated based on historical demographic data. If we wish to decompose growth rates up to age 100, say, then we will need data on fertility and mortality going back to 100+β years earlier, where β can be taken to be 45. The calculations will then allow us to assign responsibility to fertility, mortality and convergence over the past 145 years.

Returning to the original expression (1.1), $r\left(x,t\right)=r_B\left(t-x\right)+r_p\left(x,t-x\right)$ (where r_p is the proportional rate of change in survivorship in that equation), we can now insert the expression for $r_B\left(t\right)$ given in (1.4) for $r_B\left(t-x\right)$ in (1.1), letting the proportional growth rate of fertility be $r_F\left(t\right)$ to get:

$$
\begin{aligned}
r\left(x,t\right) &= r_F\left(t\right)+\frac{F\left(t-x\right)}{B\left(t-x\right)}\int_\alpha^\beta \frac{dB\left(t-x-u\right)}{dt} f\left(u\right) p\left(x,t-x-u\right) du \\
&+\frac{F\left(t-x\right)}{B\left(t-x\right)}\int_\alpha^\beta B\left(t-x+u\right) f\left(u\right) \frac{dp\left(x,t-x-u\right)}{dt} du + r_p\left(x,t-x\right)
\end{aligned}
\tag{1.5}
$$

The rate of change of fertility, $r_F\left(t\right)$, will be close to zero until the start of the fertility transition, and then will become negative while fertility falls, returning to near zero when the decline is over. This pattern can be seen in Figure 1. Letting fertility vary while holding mortality constant, the rate of change of births is roughly constant until going negative when births in 1965-69 are compared to those in 1960-64, and then declining steeply to -3% per year in recent years. The role of changes in the prior population age distribution is given by the second term on the right. The role of changes in mortality is given by the *sum of the third and the fourth terms* rather than by the fourth term alone. While the fourth term will tend to make the population older when mortality is falling, because it is larger at higher ages, the third term will tend to make the population younger when mortality is falling, because declining mortality raises the growth rate of births, which in turn makes more recent birth cohorts larger than earlier ones, making the population younger. The third effect is shown in Figure 1, where falling mortality pushes the growth rate of the number of births up above 2.5% per year by 2010. The Figure does not show the combined effect, which we will return to later (not yet included in this draft).

This partial analysis indicates the indirect effect of mortality change on the growth rate of births, which must be taken into account along with the direct effect of altered survival to older ages.

Discussion and Conclusion

If mortality change is mainly responsible for continuing population aging of the MDCs from 2005 to 2010, that would appear to imply a counterfactual: that if mortality had not declined over the past century or so, population aging today would be substantially less rapid. However, the counterfactual simulations presented here do not bear this out, either for MDCs or for LDCs, and instead point to a dominant role for fertility change as the driving force. The mathematical analysis begun here shows how the indirect effects of mortality decline lead to accelerating growth in births and tend to offset the aging effect of rising survival from birth. While it appears inevitable that the Revisionist view will apply to aging occurring at some future date, we expect that this will not be true for the dramatic increases in population aging projected over the next few decades. We have not yet checked this conjecture, but we hope to do so soon.

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Table 1. Analytic simulations of changes from 2005 to 2010 in measures of population age for India, for the simulated actual history, and for counterfactuals with a) fertility constant at 1900 level and mortality varying, and b) mortality constant at 1900 level and fertility varying

Simulated Scenario	Mean Age of Pop (Yrs)	Percent 65+ (%)	Old Age Dep Ratio 65+/20-64 (%)
Actual (Baseline)	+1.0	+0.4	+0.5
Mort varies, Fert const	-0.1	0.0	+0.1
Fert varies, Mort const	+1.0	+0.3	+0.3

Note: The baseline simulation was based on Bhat (19**) estimates of TFR and e0 for 1900-1950, and UN estimates thereafter, assuming that age specific fertility has the same age shape 1900 to 1950 as in UN data for 1950-54. The age detail for mortality was estimated by using a Lee-Carter model fit to data 1950-2010 to adjust age specific death rates to be consistent with the Bhat e0 estimates. The initial population age distribution in 1900 was taken from the 1901 Indian census. Female e0 was reduced relative to male e0. It was not possible to match the simulated population to all aspects of the UN data following 1950; we chose to match the 1950 population age distribution closely.

Table 2. Analytic simulations of changes from 2005 to 2010 in measures of population age for MDCs, for the simulated actual history (but with no migration), and for counterfactuals with a) fertility constant at 1910 level and mortality varying, and b) mortality constant at 1900 level and fertility varying.

Simulated Scenario	Change in Mean Age of Pop (Yrs)	Change in Percent 65+	Change in %Old Age Dep Ratio 65+/20-64
Actual (Baseline)	0.82	0.82	1.26
Mort varies, Fert const	0.12	0.15	0.22
Fert varies, Mort const	0.62	0.38	0.52

Note: The population of MDCs is simulated on the assumption that these populations are closed to migration, to focus attention on the roles of fertility and mortality. We take the UN population by age for MDCs in 1950 as the starting point. Preston and Stokes kindly provided their estimates of age specific mortality for MDCs from 1910 to 1950. We used this to backproject the 1950 age distribution to 1910, up to age 40.

Figure 1. A contour plot showing equi-OADR combinations of fertility and life expectancy in stable populations based on Coale-Demeny models

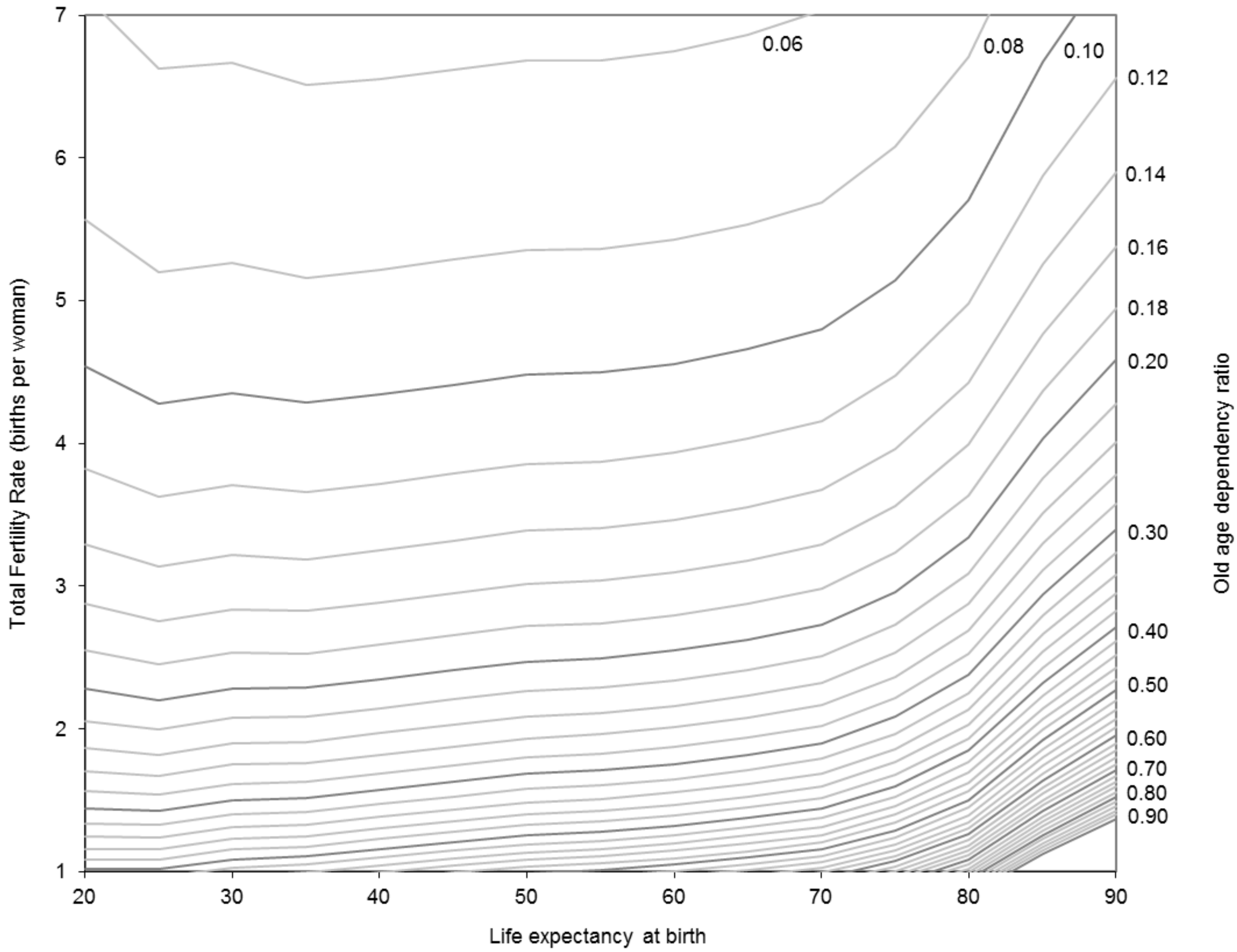


Figure 2. The growth rate of the number of births in India under three different simulation scenarios

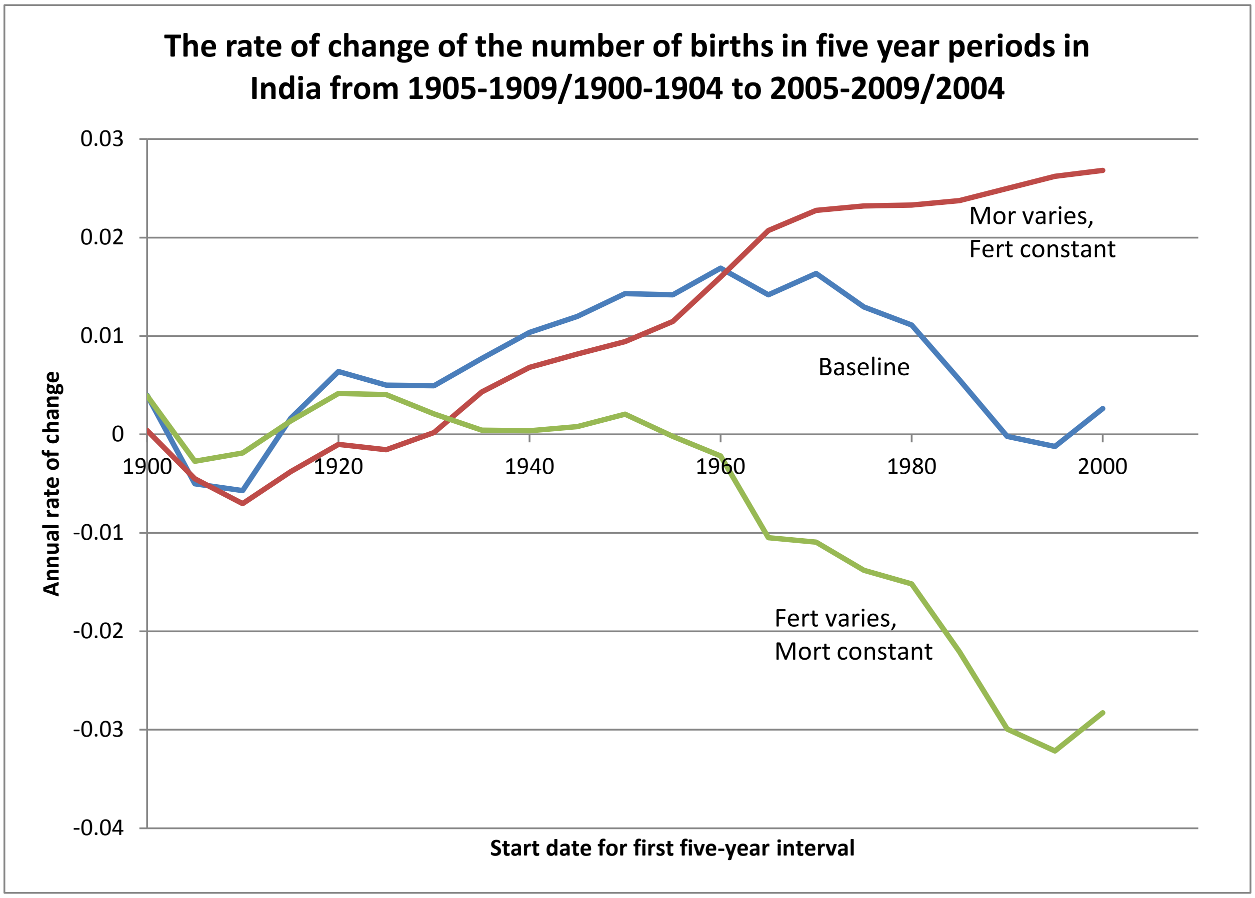


Figure 3. The rate of change of births in MDCs under three simulation scenarios

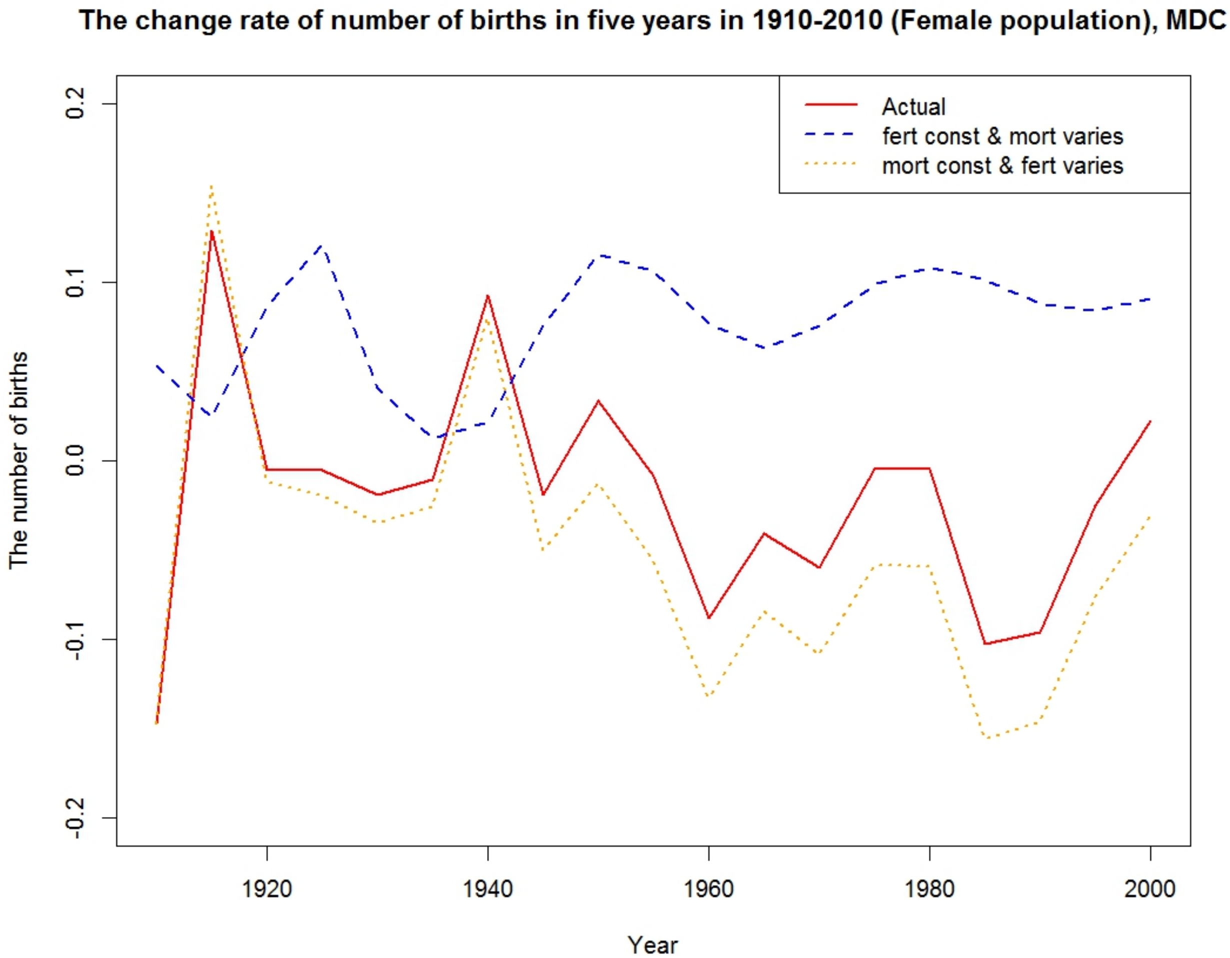


Figure 4. Simulated mean age of the population of India under three scenarios.

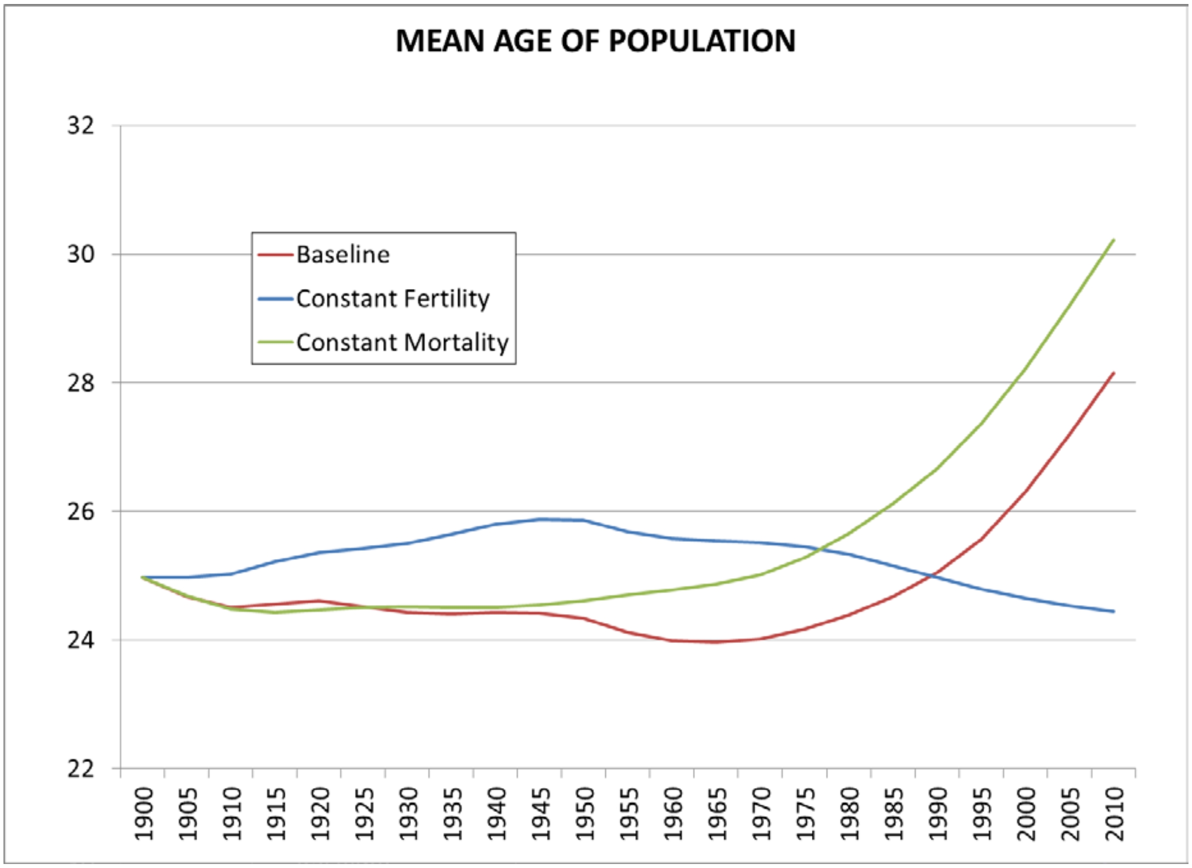
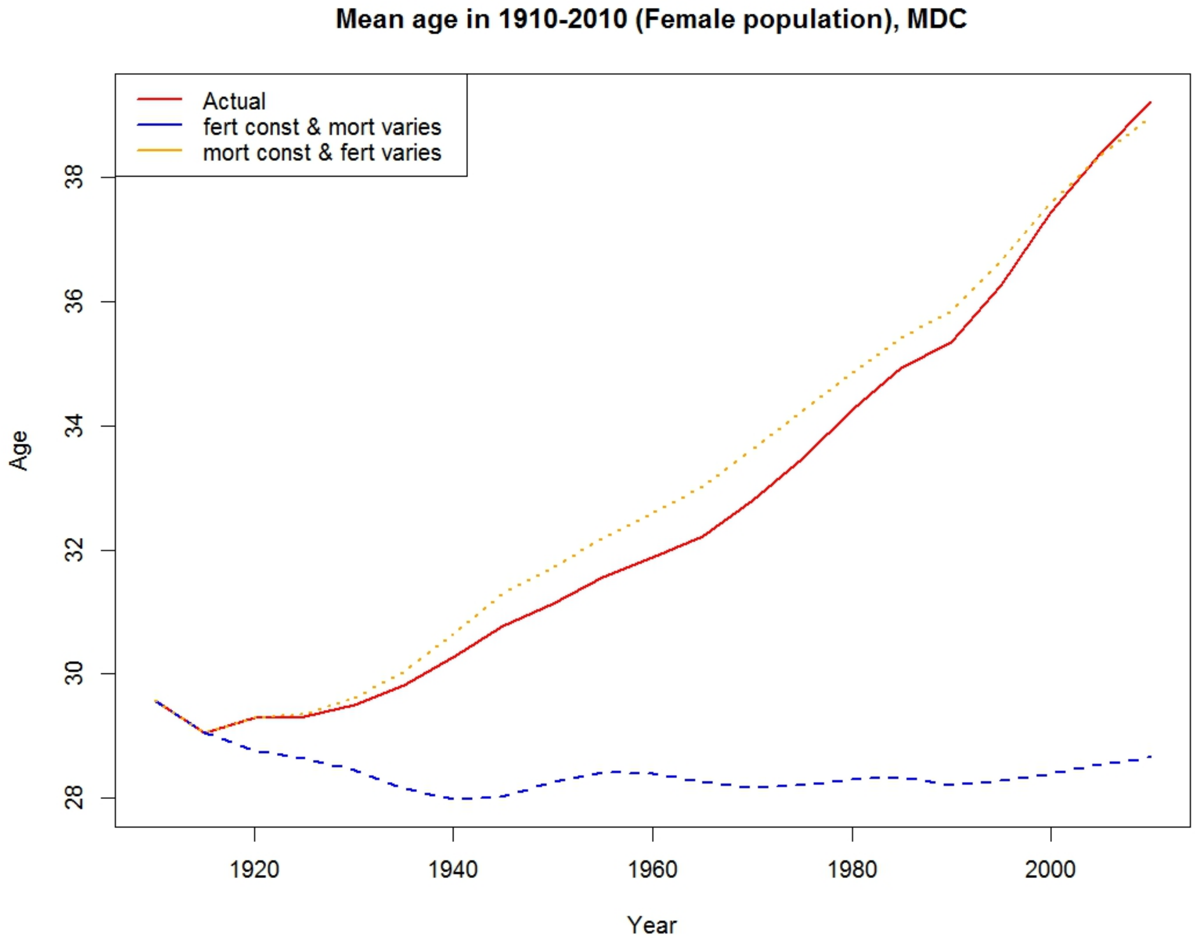


Figure 5. Simulated mean age of the population of MDCs under three scenarios.



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[i] Preston and Stokes (2012) find that in MDCs changes in mortality are the largest source of continued population aging, with a more equal distribution of responsibility in the Less Developed Countries (LDCs).