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Title

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Permalink

<https://escholarship.org/uc/item/9fn388d3>

Journal

Population and Development Review, 43(2)

ISSN

0098-7921

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Publication Date

2017-06-01

DOI

10.1111/padr.12062

Peer reviewed

Does Fertility or Mortality Drive Contemporary Population

Aging? The Revisionist View Revisited

Abstract

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.

Key words: population aging, demographic transition, stable population, fertility, mortality, age distribution

Introduction

Why are populations of rich countries now so much older than they were a century or two ago? Why are they continuing to age, and why are many developing country populations expected to age in the 21st century? Is the main driver falling mortality and lengthening life, or is it falling birth rates and slowing population growth? The answers to these questions are not straightforward. Common sense suggests that longer life drives population aging, but decades ago the work of demographers like Coale (1956, 1957) and Keyfitz (1975) persuaded us that in fact fertility decline was far more important. More recently, a new wave of demographic analysis suggests that mortality decline is the main demographic source of continuing population aging. Here we revisit this question.

Perspectives from Stable Populations

Comparative stable population analysis suggests that populations are old now mainly because their fertility has declined, and to a much smaller degree because mortality is lower. This is the Classic view, illustrated in Figure 1 which shows isoquants of the Old Age Dependency Ratio ($OADR = \text{Pop}(65+)/\text{Pop}(20-64)$) for different levels of fertility and life expectancy. Each point on the graph corresponds to a level of the Total Fertility Rate (TFR) on the vertical axis and a level of life expectancy at birth (e_0) on the horizontal axis, based on Coale and Demeny (1983, Model West Female) stable population models. Horizontal movements from left to right on this graph go from low to high life expectancy for a given level of fertility. Such movements cross few isoquants, meaning they have little effect on the OADR until e_0 reaches 70 years. By contrast

vertical movements from high to low fertility for a given level of life expectancy cross many OADR contours, indicating a strong effect on the OADR and 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 Figure 1 tells us that the OADR would have been around .08. With Europe's current TFR of 1.6 which has held quite steady over the past few decades but an unchanged life expectancy of 35, the stable old age dependency ratio would be .28, 3.5 times as high as .08. 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 current 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 appears to be mainly low fertility. The actual OADR in Europe is only .285 (United Nations, 2015). If there were no further change in vital rates (and if there were no immigration) then the European population would gradually approach the stable value, .40, over the course of many future decades.

Consider the case of India. Around 1900 the TFR was close to 6 births per woman and life expectancy was in the mid-20s, with OADR around .07 (Bhat, 1989 and Figure 1). While mortality declined, fertility remained near 6 until the later 1960s (United Nations, 2015).

According to Figure 1, the stable OADR hardly changed until the late 1960s when fertility decline began. By 2010-2014, the TFR had dropped to 2.48 and life expectancy had risen to 67.5 (United Nations, 2015), for a stable OADR of around .22 (Figure 1) while the actual OADR had

risen only from .07 to .10 (Figure 1 and United Nations, 2015). If there were no further changes in fertility and mortality, the OADR would gradually rise to its stable value of .22 in coming decades.

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 a transitional situation for which stable population models have limited relevance. 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), henceforth PS, 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 took a wrong turn when it concluded that recent population aging was mainly due to mortality decline, according a more important role to continuing mortality decline than seems consistent with the stable population comparisons. 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." (PS, 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 can we know whether the effect of earlier fertility decline has completely played out? We will consider this possibility, but reject it.

PS states 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.” This point is centrally important. Without taking account of these indirect effects, how can one say anything about the role of mortality decline in causing population aging, or about the relative roles of mortality and fertility? How do we know that the rejuvenating effect of declining mortality would offset only “some” of the aging effect and not most or all of it, or would not completely reverse the direction of the effect?

Based on this recent literature one might easily conclude that mortality decline rather than fertility decline is principally responsible for current population aging, even if the explicit comparison of the two is not always stated. If mortality decline is mainly responsible than fertility decline must have played a smaller role. We argue here that the view that mortality decline is the main driver of recent population aging is a misinterpretation of the results of these analyses, even though the analyses themselves are correct, valuable and interesting. We argue that the principal responsibility for contemporary population aging still lies with fertility, although this will change in the future.

The Revisionist View

In a closed population, the number of people alive at a given age x equals the number of people born x years earlier times the proportion of those births that survive to age x . Therefore, proportional change in the people alive at age x equals proportional change in the number of births x years earlier plus proportional change in the cohort survival rate from birth to age x . This is the starting point of the revisionist approach. Horiuchi and Preston (1988 equation 6, p.431) express this equality in continuous time, and PS (2012 equation 1, p.223) express it in discrete time. PS interpret this equation as showing that “If there have been no differences in mortality or migration rates in the lifetimes of two adjacent birth cohorts up to some particular age, then mortality and migration contribute zero to the growth rate at that age.” This conclusion is at the root of the revisionist argument. It is true if we only consider mortality following the birth of the first of the two cohorts, but it is not true if we consider earlier mortality changes as well. The reason is that mortality changes before the birth year in question can have a very important

influence on the number of births. This influence is the “indirect effect of mortality change on the annual number of births” referred to in the Preston-Stokes quote above.

The difficulty is that the process of adjustment to earlier changes in levels of fertility and mortality enters through 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 raises the population growth rate and drives up the number of births. In the developing country examples presented later, the rate of change of births stays fairly close to zero, so it appears that not much is going on. But the birth series is the dog that did not bark. The reason it did not bark is that the negative effect on the number of births of the fertility decline largely offset the positive effect of the mortality decline. Without the fertility decline, the rapid mortality decline would have led to a rapidly rising number of births and thereby would have created a very young population. The decline in fertility is the primary reason why the population is aging as it converges toward a new and older stable population age distribution.

The Appendix extends the mathematical analysis of the basic model in PS, formalizing some of the points made 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 construct counterfactuals with

constant fertility and variable mortality and with constant mortality and variable fertility, and compare these to the baseline. For simplicity we will abstract from migration and simulate populations that are closed by construction but are based on the historical fertility, mortality and initial population age distributions.

In order to analyze LDCs as a whole, PS assume that LDC populations from 1910 to 1950 are stable (2012, p.227). We instead analyze the case of India for which there are demographic estimates back to before 1900 from Bhat (1989).

Preston and Stokes focus on the change in the mean age of LDC populations between 2005 and 2010. Table 1 is based on our simulations for India and shows the change in mean age between 2005 and 2010 for the 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 table 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.

Table 1 reports a .95 year increase in the mean age of the baseline 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 almost .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, greater than the baseline 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 of births, 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 dotted line shows 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 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 indirect effect 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 mean age of the population slightly lower, as was shown in Table 1.

The dashed line shows the counterfactual in which mortality is held constant at its level in 1900 while fertility follows its actual trajectory from 1900 to 2010. As fertility began its decline in the 1960s, 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 less dramatic. With varying mortality and constant fertility, the rate of growth of births rises somewhat from left to right whereas with varying fertility and constant mortality 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 changes in mean ages shown in the first column of Table 1 are based on the change between the last two points of these plots for each scenario. In these simulations, 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.ⁱⁱ

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

Population Aging and United Nations Projections for the 21st Century

Based on our analytical simulations of India and MDCs, we find that fertility change plays a dominant role in the population aging of the past century, consistent with the Classic view. On the other hand, we also agree that, as fertility rate reaches a stable level and life expectancy keeps increasing in the future, mortality change will become increasingly influential. Here we use UN population projections to investigate the sources of change in population structure over 2015-2100.

Figure 6 shows the growth rates of the number of births for three UN projection variants -- medium, constant fertility, and constant mortality-- for MDCs, India, China and Sub-Saharan Africa. For MDCs and China, the medium-variant curve is very close to the curve of the constant-mortality variant. Evidently, projected mortality change has almost no impact on the growth rate of the number of births because the chance of surviving to reproductive age for females is already relatively high in these countries. In contrast, there is a significant gap between the medium-variant projection and the constant-mortality projection for India and Sub-Saharan Africa. That is, declining mortality will still boost population growth rates in LDCs because more births will survive to reproductive age. The indirect effects of mortality decline will be relatively small for MDCs and China. But for India and Sub-Saharan Africa, the indirect effects will be sizable and reduce the mean age of the population.

The mean ages for MDCs, India, China and Sub-Saharan Africa are presented in Figure 7.

Because the current fertility rates of MDCs and China are significantly below the replacement

rate, their mean ages in the scenario of constant fertility are older than the other two scenarios. In other words, if MDCs and China continue their current low fertility, they will have older populations than the medium-variant UN populations. Unlike in the 1910-2010 simulation (see Figure 4), the population of India will be getting older in the constant-fertility projection. However, the constant-fertility projection is below the constant-mortality projection. This shows that fertility change will still play a dominant role for population aging in India. Figure 7(d) expresses the corresponding results for Sub-Saharan Africa, where the medium-variant mean age tracks the constant-mortality mean age projection quite well, while the constant-fertility projection remains flat. This pattern is quite similar to our 1910-2010 simulation (see Figure 5) for MDCs.

Table 3 focuses on changes in mean age across the last five-year period of the projections, from 2095 to 2100, just as Tables 1 and 2 focused on the five-year period 2005-2010. However, unlike those tables, which looked at the last five-year period of projections covering 110 years, Table 3 is based on projections that cover only 85 years, from 2015 to 2100 which is too short a span to consider fully the roles of fertility and mortality change over this period, but for practical purposes probably gives a very good idea of the full outcome.

For MDCs, India and China, the Constant Fertility variant accounts much better than Constant Mortality for the Medium change between 2095 and 2100. For Sub-Saharan Africa, the opposite is true, because it is still at an early stage of the demographic transition.

Discussion and Conclusion

As we see it, the assertion in PS that mortality change is mainly responsible for continuing population aging of the MDCs from 2005 to 2010 implies 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. However, an adherent of the revisionist approach might respond that the correct counterfactual would actually be constant mortality (at least for those cohorts still alive in 2005 to 2010) together with a constant rate of growth of the number of births over the century. This alternative counterfactual would be appropriate for a restricted claim that ignored the indirect effects of mortality decline on the growth rate of births. This partial claim, by abstracting from indirect effects, would be consistent with our view that fertility decline is the main demographic source of contemporary aging, while the role of mortality decline is relatively modest.

Policy makers should be aware that fertility decline, particularly to low levels, is largely responsible for past and current population aging, regardless of mortality trends. This will continue to be true for populations of the world that are relatively early in the Demographic Transition, such as most of Sub-Saharan Africa. However, for most of the global population future changes in fertility will likely be smaller than in the past. At the same time, the indirect effects of mortality decline on the growth rate of births are diminishing toward zero in many parts of the world. Unless fertility becomes unexpectedly volatile in the future, mortality change

is likely to drive population aging in the future. Our comparison of the UN projection variants bears out this view for continuing aging from 2095 to 2100, except in Sub-Saharan Africa.

References

- Arthur, Brian W. and James W. Vaupel. 1984. "Some general relationships in population dynamics." *Population Index* 50(2): 214-226.
- Bhat, Mari P.N. 1989. "Mortality and fertility in India, 1881-1961: A reassessment", in T. Dyson (eds.), *India's Historical Demography: Studies in Famine, Disease and Society*. London: Curzon Press, pp. 73-118.
- Caselli, Graziella and Jacques Vallin. 1990. "Mortality and population ageing" *European Journal of Population* 6(1): 1-25.
- Coale, Ansley J. 1956. "The effects of changes in mortality and fertility on age composition" *The Milbank Memorial Fund Quarterly* 34(1): 79-114
- Coale, Ansley J. 1957. "How the age distribution of a human population is determined" *Cold Spring Harbor Symposia on Quantitative Biology* 22: 83-88.
- Coale, Ansley and Paul Demeny. 1983 *Regional Model Life Tables and Stable Populations (2nd Edition)*. Academic Press.
- Horiuchi, Shiro and Samuel H. Preston. 1988. "Age-specific growth rates: The legacy of past population dynamics," *Demography* 25(3): 429-441.
- Horiuchi, Shiro. 1991. "Assessing the effects of mortality reduction on population ageing," *Population Bulletin of the United Nations* 31/32: 38-51.

- Keyfitz, Nathan. 1975. "How do we know the facts of demography?" *Population and Development Review* 1(2): 267–288.
- Lee, Ronald D. 2011. "The outlook for population growth" *Science* 333(6042): 569-573
- Preston, Samuel H. 1974. "The effect of mortality change on stable population parameters." *Demography* 11(1): 119-130.
- Preston, Samuel H. and Andrew Stokes. 2012. "Sources of population aging in more and less developed countries" *Population and Development Review* 38(2): 221–236
- Preston, Samuel H., Christine Himes, and Michael Eggers. 1989. "Demographic conditions responsible for population aging," *Demography* 26(4): 691–704.
- United Nations Population Division. 2015. "*World population prospects, the 2015 revision,*" New York: United Nations Department Economic and Social Affairs.
https://esa.un.org/unpd/wpp/publications/files/key_findings_wpp_2015.pdf. Accessed 15 Jan 2017.

Appendix. Analysis of the Basic Equation

111Equation Chapter 1 Section 1The purpose of this analytic appendix is to expand the analysis given in PS (2012) to show how the indirect effects of mortality arise and to include them in the analysis. PS presents the following result in discrete notation that we here re-express in continuous form:

$$212\backslash^* \text{MERGEFORMAT } (.) \quad r(x,t) = r_b(x,t) + d[\ln p(x,t-x)]/dt + d[\ln j(x,t-x)]/dt$$

On the left is the rate of growth of the population at age x in time t (not longitudinally, but as the population at the 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 . 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.

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. As shown in the general framework by Arthur and Vaupel (1984), the age distribution

of a time-varying population in a certain time depends on the life-cycle behavior in the past as well as that at that time. 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.

We will 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 we 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:

$$313 \backslash * \text{MERGEFORMAT } (.) \quad B(t) = \int_{\alpha}^{\beta} B(t-x)m(x, t) p(x, t-x) dx$$

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

$$414 \backslash * \text{MERGEFORMAT } (.) \quad B(t) = F(t) \int_{\alpha}^{\beta} B(t-x)f(x) p(x, t-x) dx$$

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

$$\begin{aligned}
\frac{d \ln [B(t)]}{dt} &= \frac{1}{B(t)} \frac{dB(t)}{dt} \\
&= \frac{1}{B(t)} \left[\frac{dF(t)}{dt} \frac{B(t)}{F(t)} + \frac{1}{F(t)} \left(\int_a^x \frac{dB(t-x)}{dt} f(x) p(x, t-x) dx + \int_a^x B(t-x) f(x) \frac{dp(x, t-x)}{dt} dx \right) \right] \\
&= \frac{d \ln [F(t)]}{dt} + \frac{F(t)}{B(t)} \int_a^x \frac{dB(t-x)}{dt} f(x) p(x, t-x) dx + \frac{F(t)}{B(t)} \int_a^x B(t-x) f(x) \frac{dp(x, t-x)}{dt} dx
\end{aligned}$$

From this we see that the proportional rate of change in the number of births at

time t , $r_B(t)$, is the sum of three terms. The first is the proportional rate of change of the TFR at time t . The second term expresses the effect on current births of historical changes in number of reproductive age women, taking into account their births rates at that time. The third term reflects the influence of changes in the proportion surviving from birth to reproductive ages, taking into account fertility at that time.

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, perhaps starting around 1800. 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 $100 + \beta$ 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 Error: Reference source not found,

$$r(x, t) = r_B(t - x) + r_p(x, t - x) \quad (\text{where } r_p \text{ is the proportional rate of change in}$$

survivorship in that equation), we can now insert the expression for $r_B(t)$ given in

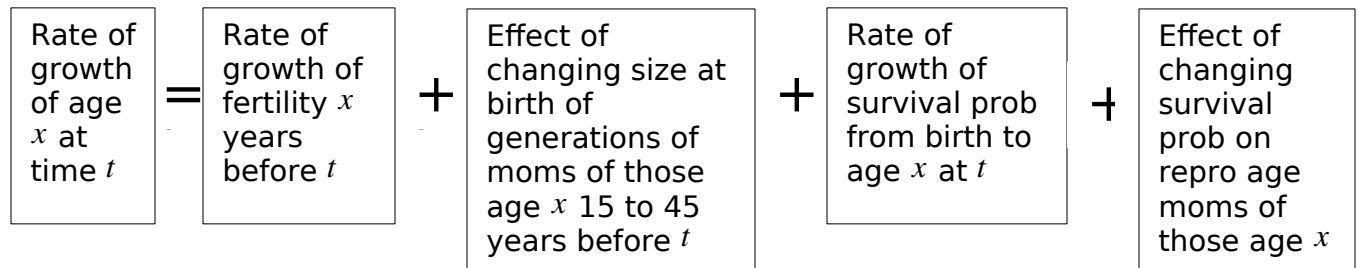
Error: Reference source not found for $r_B(t - x)$ in Error: Reference source not found,

letting the proportional growth rate of fertility at time t be $r_F(t)$ to get:

$$r(x,t) = r_f(t-x) + \frac{F(t-x)}{B(t-x)} \int_a^y \frac{dB(t-x-u)}{dt} f(u) p(x,t-x-u) du$$

$$+ \frac{F(t-x)}{B(t-x)} \int_a^y B(t-x+u) f(u) \frac{dp(x,t-x-u)}{dt} du + r_p(x,t-x)$$

616* MERGEFORMAT (.)



The first term on the right reflects the rate of change of fertility x years earlier,

when these x -year olds were born. The rate of change of fertility, $r_f(t)$, 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. The second term reflects the effect of the number and age distribution of reproductive age women x years earlier, as it is influenced by prior variations in the number of births of which these women are the survivors under initial mortality conditions. The third term reflects the effect on these reproductive age women x years earlier of the changing survival from birth to the relevant age. This is the *indirect* effect of mortality decline, tending to raise the number of births by raising the number of surviving women. Finally, the last term reflects the *direct* effect of mortality decline, that is the rate of change of the probability of surviving from birth x years earlier to age x at time t . The full 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.

In equations (1.4) and (1.5) changes in mortality have both a direct effect, the fourth term on the right, and an indirect effect, in the third term. An indirect effect of fertility change does not show up explicitly because these equations take B as given for periods before $t - \alpha$. In an expanded analysis in which the initial population age distribution was pushed back to an earlier time, indirect fertility effects would also occur. Past increases (decreases) more than 2α years ago would increase (decrease) the number of reproductive age females more than α years ago, and thus have a reinforcing indirect effect in addition to the direct effect of fertility change on births at t . For mortality, however, the direct and indirect effects work in opposite directions, tending to offset one another.

Interactions are a different issue. Interactions occur in our simulation results because we are looking at finite and large changes, not at the infinitesimal changes of calculus for which interactions conveniently vanish. In our simulations interactions appear as the differences between the total change and the sum of the changes due to each of fertility and mortality holding the other constant. Sometimes these interaction effects are rather small, as in Table 1, but they can also be rather large as in the last two columns of Table 2. This occurrence is familiar to demographers, and there are different ways of allocating the interaction to the individual variables.

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	Change in Mean Age of Pop (Yrs)	Change in Percent 65+ (%)	Change in OADR: 65+/20-64 (%)
Actual (Baseline)	+0.95	+0.40	+0.46
Mort varies, Fert const	-0.09	+0.02	+0.09
Fert varies, Mort const	+1.01	+0.31	+0.29

Note: The baseline simulation was based on Bhat (1989) estimates of TFR and e_0 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 e_0 estimates. The initial population age distribution in 1900 was taken from the 1901 Indian census. Female e_0 was reduced relative to male e_0 . 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 1910 level and fertility varying.

Simulated Scenario	Change in Mean Age of Pop (Yrs)	Change in Percent 65+ (%)	Change in OADR 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. PS 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.

Table 3. Comparisons of changes from 2095 to 2100 in mean age of population for MDCs, India, China and Sub-Saharan Africa under UN projection variants from baseline 2015: Medium, Constant Fertility, and Constant Mortality

United Nations Variant	Change in Mean Age of Pop (Yrs) 2095 to 2100			
	MDC	India	China	Sub-Saharan Africa
Medium	0.235	0.487	0.239	0.848
Constant Fertility	0.262	0.239	0.537	-0.015
Constant Mortality	0.000	0.090	-0.184	0.626

Figure 1. A contour plot showing equi-OADR combinations of fertility and life expectancy in stable populations based on Coale-Demeny (1983) models

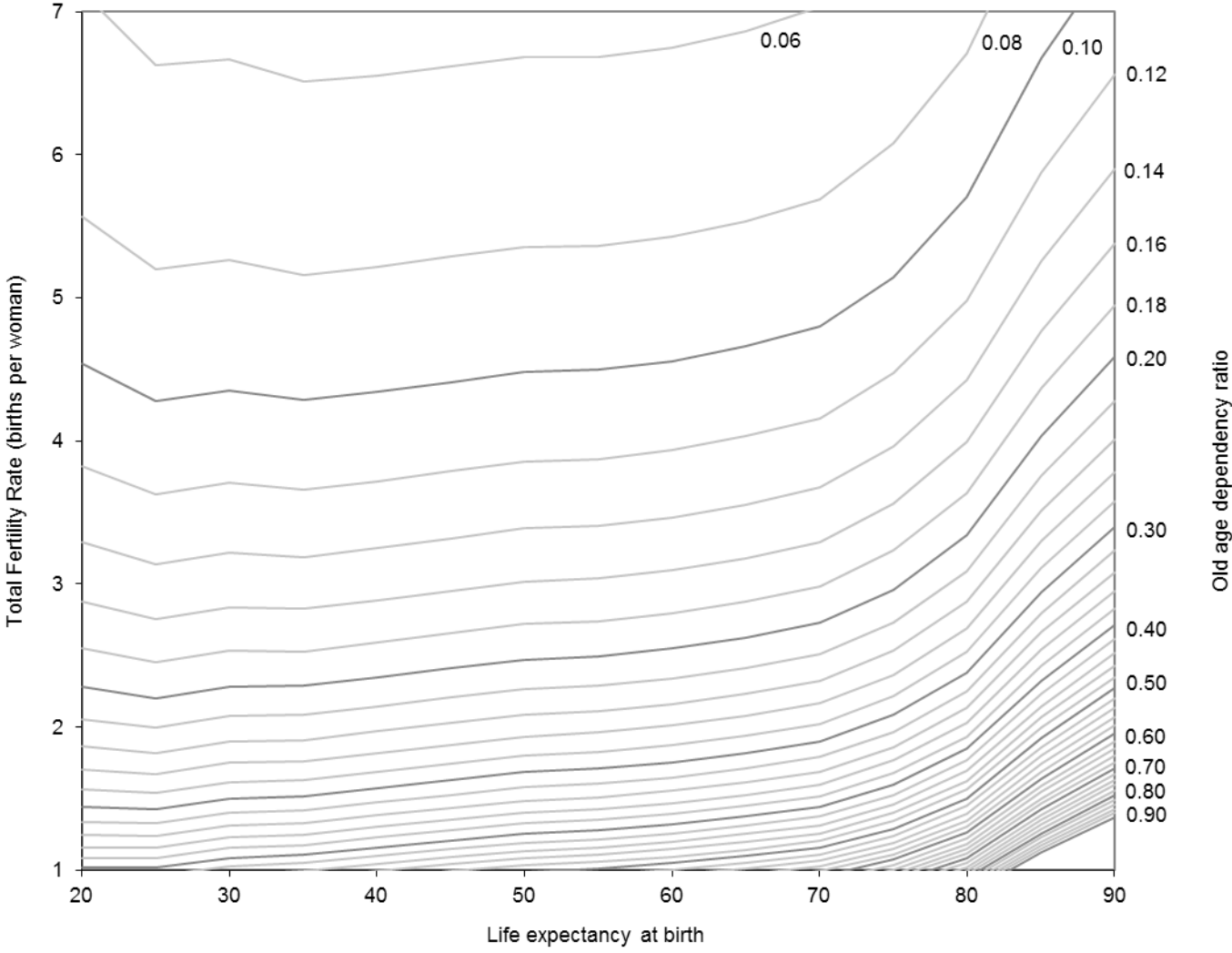
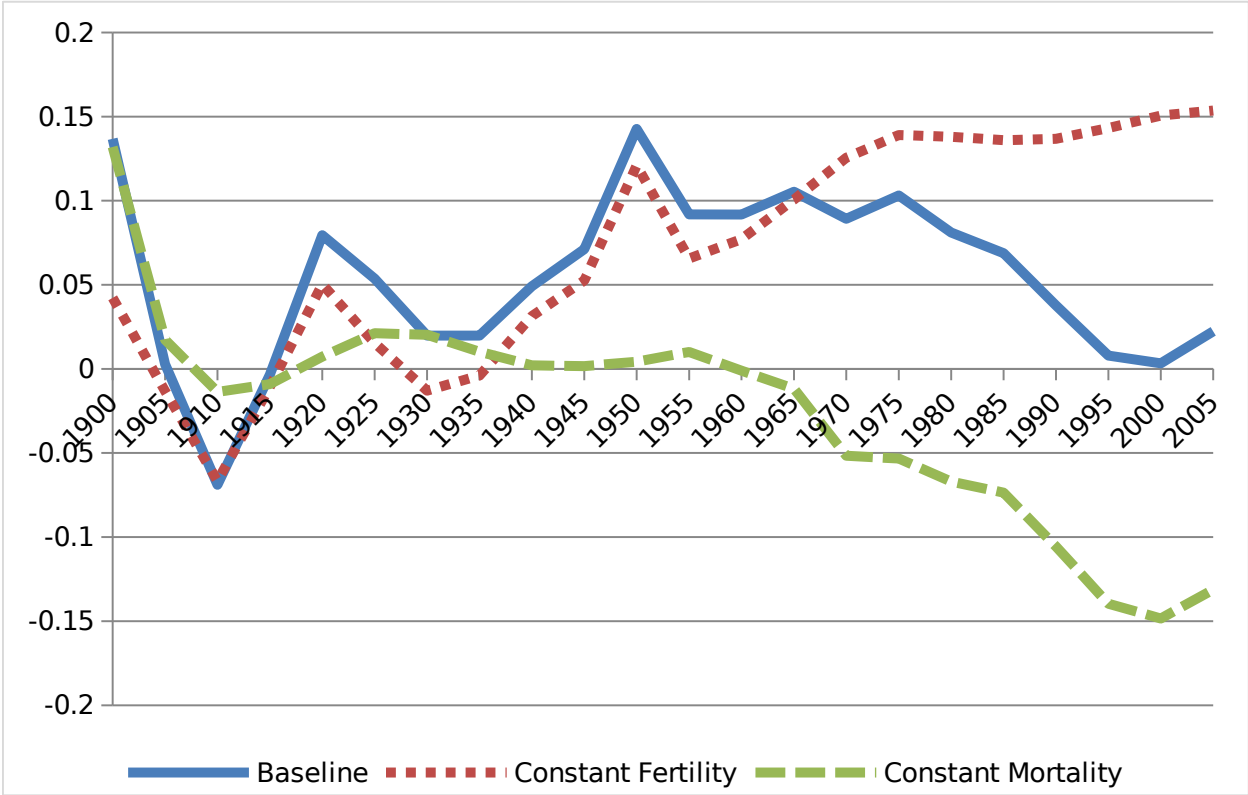
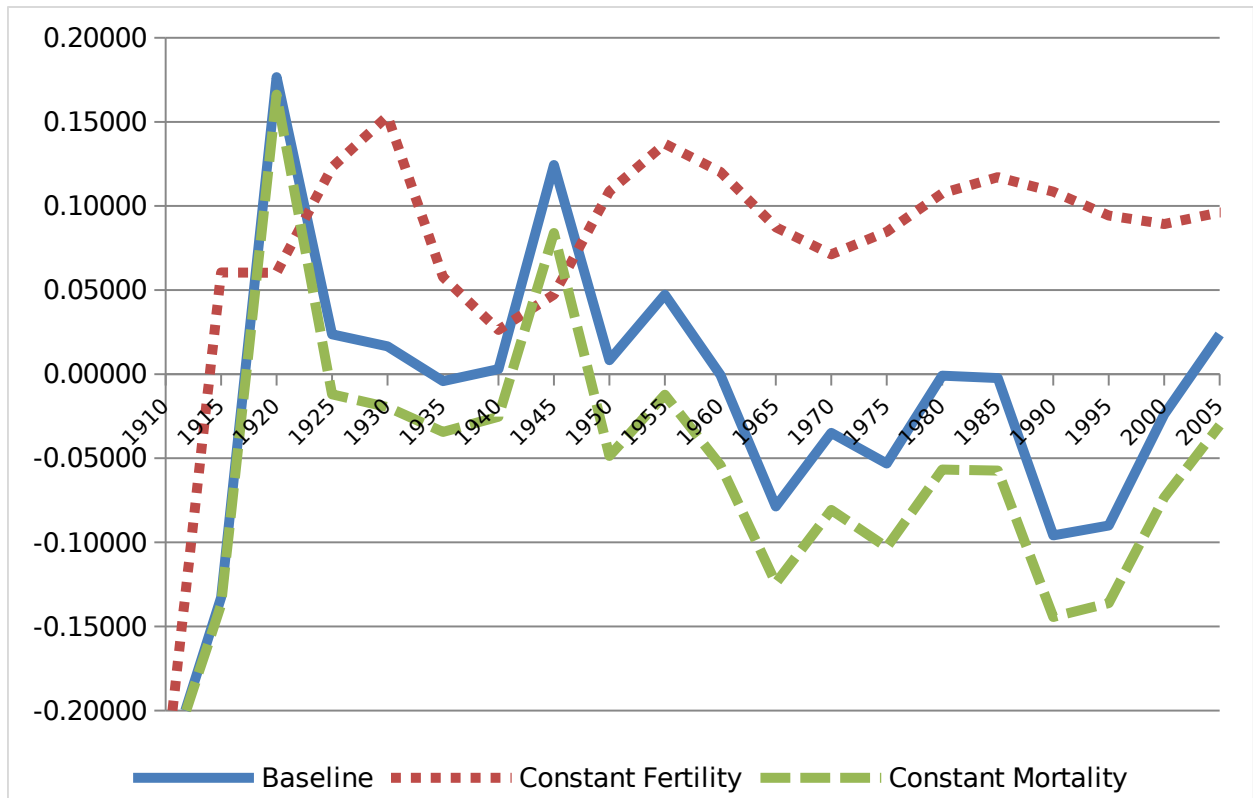


Figure 2. The growth rate of the number of births in India under three different simulation scenarios



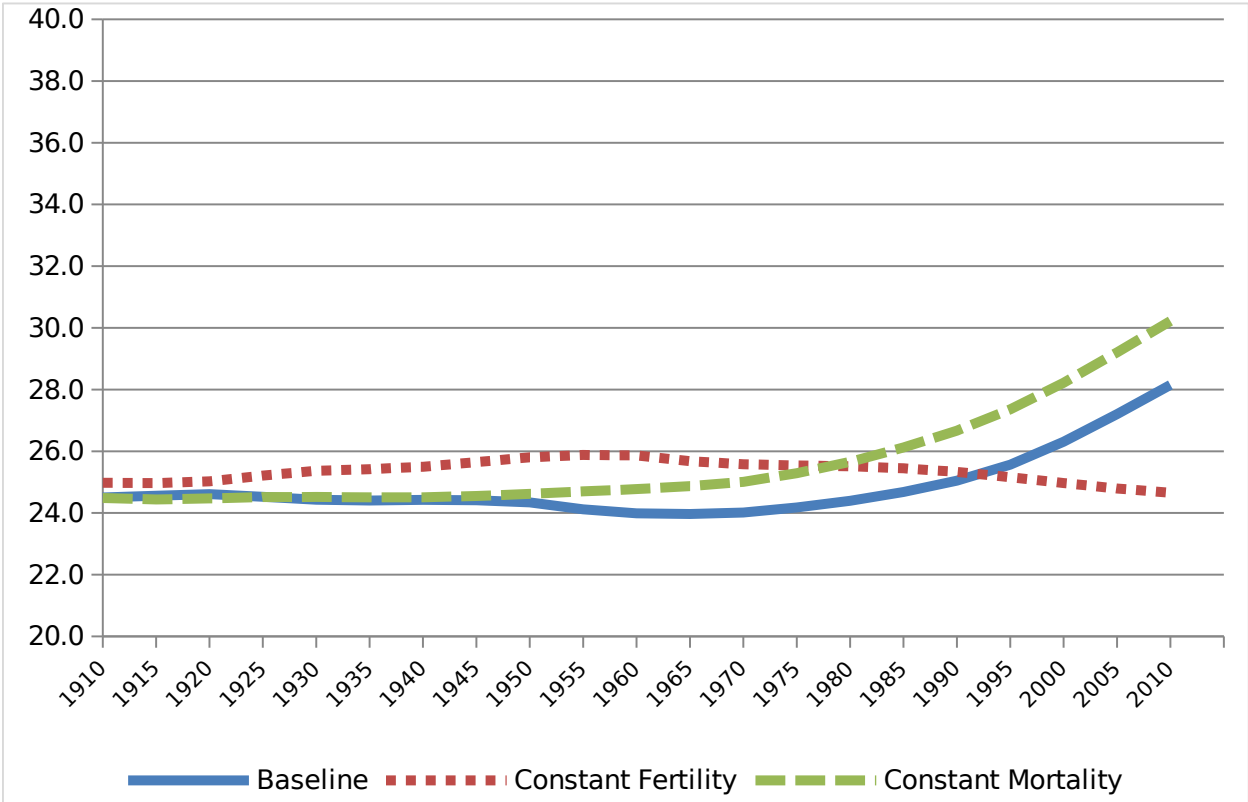
Note: For simulation assumptions, see text.

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



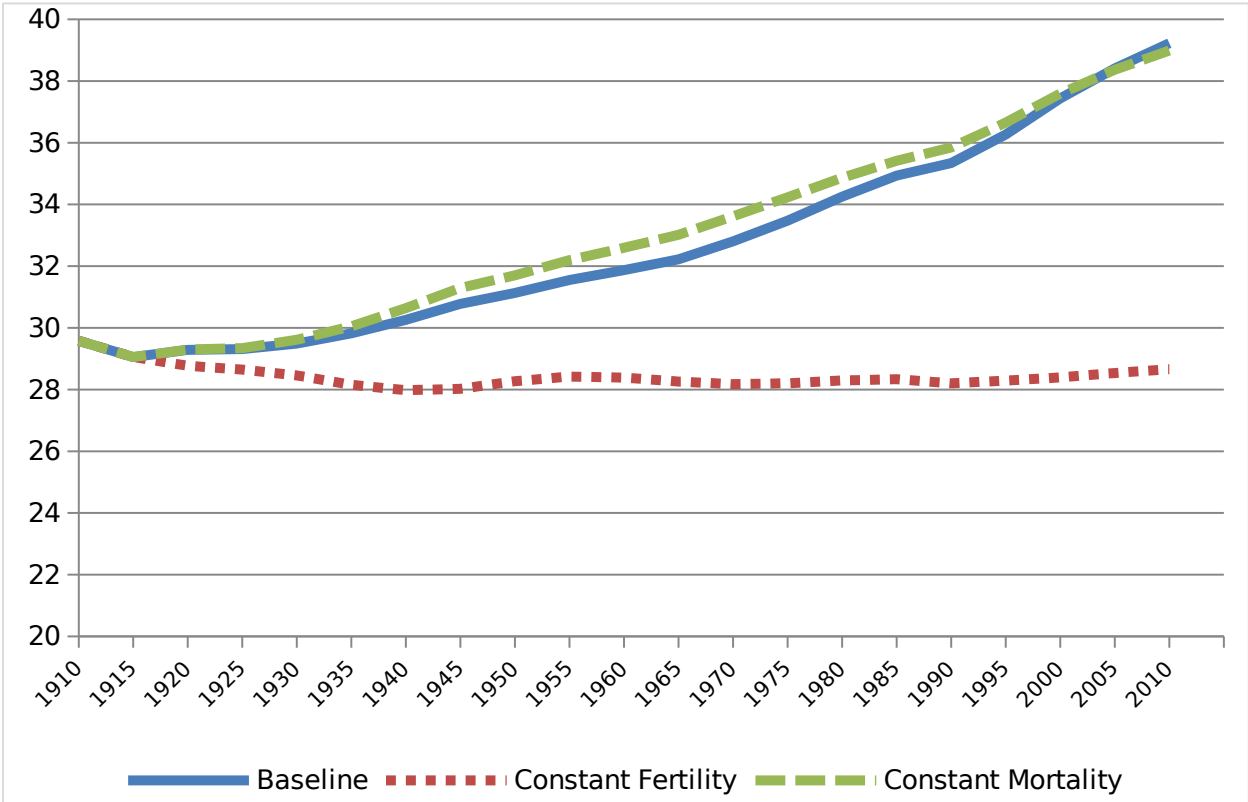
Note: For simulation assumptions, see text.

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



Note: For simulation assumptions, see text.

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



Note: For simulation assumptions, see text.

Figure 6. The growth rate of the number of births in MDCs, India, China and Sub-Saharan Africa, 2015-2100

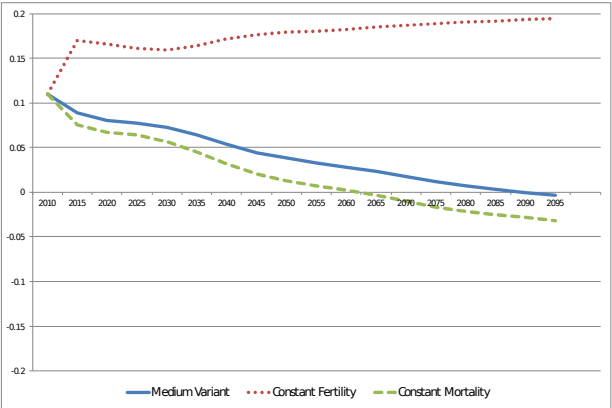
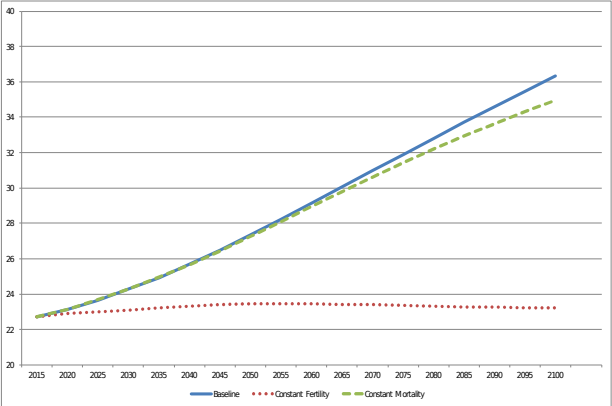


Figure 7. The Mean Age of Population in MDCs, India, China and Sub-Saharan Africa, 2015-2100



- 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).
- ⁱⁱ The simulated baseline mean age for India corresponds very closely to the mean age based on United Nations age distributions for India from 1950 through 2010.