Shapes and Limits of Longevity in Mexico*

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1. Increasing Longevity

There has been an increasing interest in the growth of the developed world's extremely old population, most recently of those aged 100 and over (Vallin et Meslé, 2001). The focus on the centenarians of Europe, North America and Japan has created concepts about *longevity* and its meaning, along with the formulation of theories and the construction of indicators. One of the arising issues is related to how long a human being can live, to which an emblematic act of western faith is Methuselah, who is said to have lived 969 years. Greek mythology is more ambitious, and the gods of Olympus live forever keeping the same age, from the youth and beauty of Venus to the maturity and might of Zeus (Wachter, 1997). In our time, based on fully documented facts and without any controversy about who has lived the longest, the official record belongs to Jeanne Calment, who died in 1997 at 122. This establishes *the maximum length of life observed*. Reviewing records and statistics of the oldest-old, the discussion generates the theoretical concept of *maximum longevity*. This concept refers to the existence of a limit age that somebody someday may attain but that nobody may surpass (Carey, 2003).

Moving from individuals to the collective and from developed societies to less developed countries, *life expectancies* and their increases are a known method to measure longevity and its changes. By the middle of the 20th century, life expectancy at birth was 51.4 years in Latin America and 69.0 in North America. By the end of the century these figures turned into 69.2 and 76.9, respectively. According to current demographic tendencies and based on assumptions about the social and economic developments that affect mortality, forecasts for the middle of the 21st century suggest figures of 77.6 and 81.9 (UN, 1999). But there are also beliefs about getting to life expectancies of 100 and over by 2050.

The following questions are related to how much life expectancy can increase and under which circumstances it may occur. Answers point out that mortality improvements are slowing down and are more difficult to achieve. To have a life expectancy at birth of 85 years, eliminating all avoidable causes of death is necessary (Fries, 1980). Beyond those boundaries, a life expectancy above 90 years implies reducing almost all causes of death to close to zero (Olshansky & Carnes, 2001); that is the elimination of cancer, heart disease, diabetes and other illness that today are incurable. However, some research and projects predict the replacement of organs and tissues through prosthetics, synthetic materials and animal parts; better drugs based on nanotechnology; and primarily genetic manipulation. The scientists working on these objectives are generating confidence that a significant extension of life is achievable, including doing so in better health. Although human intervention itself has been modifying the course of the human race as an evolutionary species for some time now, only recently has it become apparent that biotechnology, more than natural causes, will be the decisive element for the future of our own evolution with paramount consequences (Fukuyama, 2002). The less controversial implications will be the increased life span, extended longevity and higher life expectancy.

In the case of Mexico and other less developed countries, some tasks are more important than the use of sophisticated medical and biological technologies. They are to attain the stages of higher economic development and social equality that would translate in the extension of longevity, increases in life expectancy and better perspectives in health and well-being for the elderly, the oldest-old and the rest of the population.

2. The Increasing Importance of the Oldest-Old

In population and housing censuses in Mexico before the most recent one dating from 2000, reports and published tables of common data involving age distributions used "65 years and over" as the last open age bracket. In the 1990 census, for some statistics this bracket extended to "75 and over." In a similar fashion, demographic data as widespread as those found in life tables and population projections from the United Nations Population Division use "80 and more" as the last category (UN, 1999). There was a time when the oldest-old population was so small that it was of no major concern for social and planning issues. Statistics up to "80 and over" were sufficient for almost all practical purposes of demographic description, analysis and forecasting. Now, the oldest-old sectors are growing in percentage and absolute numbers, bringing up specific and well-defined problems in economic security and health care of escalating consequences. Therefore, the demand for more specific information makes it necessary to move the last open group to higher ages. This feature is now common in more recent statistical reports and publications. As a result of these tendencies and considerations, the 2000–50 life tables and projections of the Mexican population from the National Population Council (Consejo Nacional de Población – CONAPO) get to ages 100 and over (CONAPO, 2002).

By looking close into longevity we are not just trying to include more age brackets into population statistics. We're trying to enter into grounds of demographic, social, economic and health issues not yet explored that will have repercussions in the application of population policies, social security planning, health delivery and actuarial practice. To a great extent, factors determining population aging and its consequences are still waiting for theoretical frameworks and new sources of information appropriate to demographic and actuarial studies fitted to our changing demographic, social and economic environment. The analysis and interpretation of the qualitative and quantitative meaning of these factors are already essential matters.

Although it is true that changes in fertility and migration affect demographics and are determinant in the percentage of the elderly population, it is also clear that the reduction of mortality is by far the most significant factor in the aging process. In terms of the elderly population forecasts, we are aware that participants in the age group "60 and over" for the next 60 years have already been born. The size of this group will be affected only by mortality and migration but will not be changed by birthrate. We can add to these considerations the fact that the importance of migration on those ages is relatively minor, leaving demographic perspectives of the elderly population for the next 60 years as a topic mainly related to the complementary nature between mortality and survival.

In this paper we introduce the discussion about the levels and forms that mortality and survivorship are taking for the oldest-old in Mexico. Indirect estimates are required because of limited information. The aim is to underscore the need to better understand the characteristics and dynamics of longevity. Some questions are raised in relation to mortality of the elderly, how it has been in the past, how it is expected to develop, and how to recognize and project mortality rates for the oldest-old. Of greater relevance is how changes in mortality patterns are reflecting on the survival to 100 and beyond. Additional questions are proposed and some answers are suggested about which could be the limits of life expectancy and longevity.

3. How Many Centenarians Are There?

Using estimated and projected mortality along with corrected amounts and age distribution of population in census data, we can suggest paths about past and future statistical behavior of centenarians. Figures in Table 1 come from crude data just as they were obtained in each of the population censuses from 1930 to 2000.

TABLE 1

	Total Population, Population 100+, Ratio Total/100+ **Crude and Corrected Data (1930-2000), Projections (2010 to 2050). México.**					
	Raw census data			**Corrected census data**		
Year	**Total**	**100 +**	**Tot/100+**	**Total**	**100 +**	**Tot/100+**
1930	16,552,722	2,835	5,839	16,902,324	7	2,414,618
1940	19,653,552	2,946	6,671	20,259,492	12	1,688,291
1950	25,791,017	6,174	4,177	26,218,970	27	971,073
1960	34,923,129	22,762	1,534	35,608,725	689	51,682
1970	48,225,238	10,950	4,404	49,735,453	1,228	40,501
1980	66,846,833	15,103	4,426	66,558,832	1,851	35,955
1990	81,249,645	16,559	4,907	83,480,022	2,779	30,036
2000	97,483,412	19,757	4,934	99,818,193	6,953	14,356
				Projections 2010-2050		
2010				112,509,758	12,761	8,817
2020				122,475,398	20,880	5,866
2030				129,411,713	42,349	3,056
2040				132,836,631	77,589	1,712
2050				132,444,397	137,295	965
Data: Population and housing censuses, 1930 to 2000. Demographic projections 2000-2050, CONAPO						

The left-hand side of the table shows population totals, the number of people aged 100 and over and the number of inhabitants per centenarian. If such numbers were true, from the 16,552,722 inhabitants in 1930, 2,835 were 100 and over, that is one in every 5,839. In 1950, this ratio between centenarians and the total population is 4,177. In 1960, the relationship has a notorious reduction to 1,534 because of the greatest number of declared centenarians, which is 22,762 out of a total population of 34,923,129. Between 1970 and 2000 there is a spurious stability in the ratio of total population over the number of centenarians, going from 4,404 to 4,934. Such figures would imply mortality patterns corresponding to life expectancies at birth well above 80 years for both sexes in all those years, certainly far from what it is reasonably and actually experienced.

These figures are a clear example of biased answering to the census in the form of a widespread and well-known age overstatement among the elderly (Myers, 1940) that results in an inexistent higher number of centenarians. This is also a bias in developed countries, although at a lower level (Buettner, 2001). As part of this trend, in Mexico the oldest people show a digit preference while declaring their age, choosing 0 and also 5 to a lesser extent. It is not that actual ages are around the preferred digit but that it is a bias toward a higher age that widens as age increases (Del Popolo, 2000). The practice of declaring a higher age also affects deaths registration, leading to lower mortality estimates (Grushka, 1996).

As part of the handling and presentation of population statistics, for both demographic reconstruction of the past and prospectives in the calculation of projections, it is important to have census corrections and coherent demographic series, including mortality behavior. Following CONAPO's harmonization of census data and grading of demographic parameters, on the upper right-hand side of Table 1 we have the estimated size of the total population, the number of centenarians and number of inhabitants for each person aged 100 and over.[1] These estimates reflect at least logical statistical patterns, better approximations of what may actually happen and what is hypothetically feasible to occur for the first half of the 21st century. In 1930 centenarians were scarce, estimated at one in every 2.5 million inhabitants. Numbers grew during the following decades, and by 2000 centenarians became relevant because they make up one of every 14,356 inhabitants. Following the trend, the bottom right side of the table projects that centenarians will be numerous in the coming decades. By the middle of this century one for every 1,000 people is estimated.

4. q_x and d_x Patterns Beyond 100

Although the various demographic projections from different agencies highly coincide in the models and methodology employed, the assumptions on the forecasted behavior of demographic components vary. Thus, the results differ and even give way to debates.[2] However, the projections prepared by CONAPO use better methodology, are coherent over a long period and are accessible not only in their final results but also in their background assumptions, statistics used and intermediate results. Thus, based on the studies by J. Gómez-de-León and V. Partida about the reconstruction of mortality patterns in Mexico (Gómez-de-Léon & Partida, 1993), we have a set of mortality tables for every calendar year in the period from 1930 to 2000, with projections up to 2050 (CONAPO, 2002). This set of data is the only one that looks at the development of the demographic components through a considerable period of time with projections based on that continuity within the social and economic context of Mexico.[3] This paper is largely based on this available information in an approach suggesting some inferences and assumptions about the mortality of the oldest-old. Somehow it stretches the methods used by CONAPO.[4]

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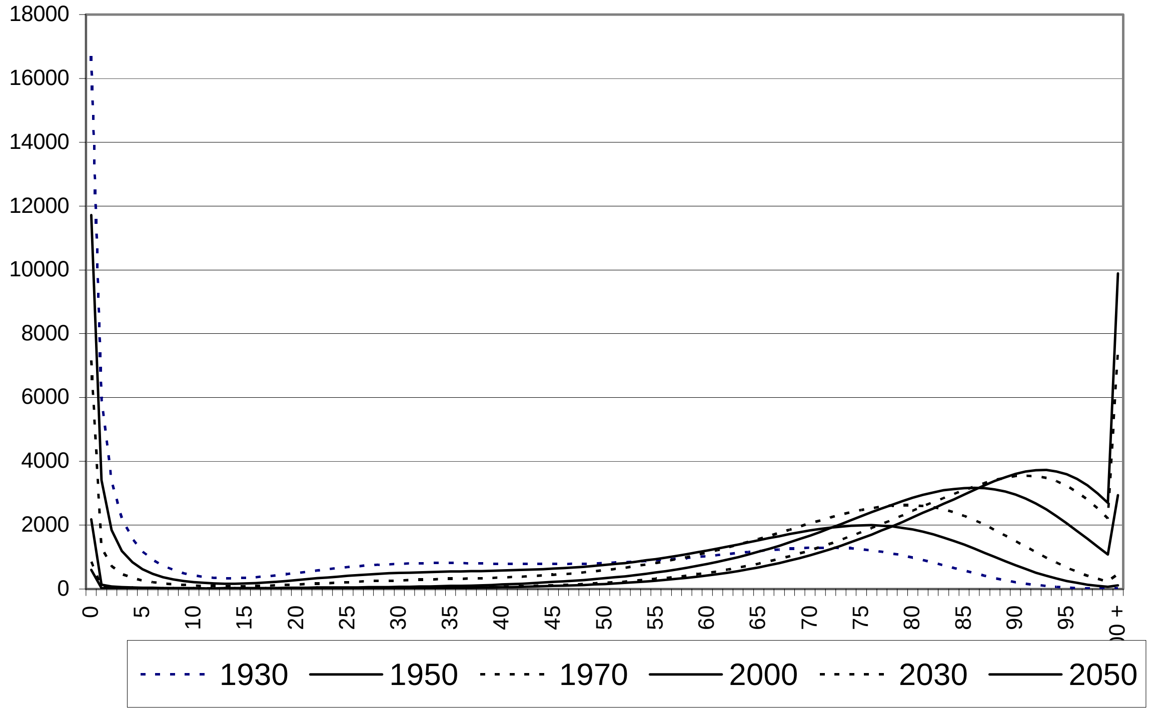
[1] It is important to note that in this document we analyze the only source of information publicly available for the subject under study.
[2] The greatest controversy is about the level of total fertility rate.
[3] Population projections and their assumptions over future mortality, fertility and migration are always under revision and updating. Variation of parameters within reasonable limits and their resulting scenarios do not affect the purposes and conclusions in this paper.
[4] Similar exercises may be produced using other estimates and projections of mortality.

Graph 1 is an example of changes in mortality patterns based on the evolution of the d_x function in female mortality tables for the years 1930, 1970 and 2000 and on its expected outline for 2030 and 2050. The results for the male population have analogous data and a similar graph. The chart highlights two aspects. In the first place, it illustrates the aging process through the move of mortality towards older ages. The appalling high infant mortality of the first half of the past century had a remarkable fall down in a shift of mortality heading for senility by the end of that century.

Graph 1
dx in men; Mexico 1930 - 2050



The other characteristic to be noted is that as a direct representation of data that has "100" and over as the last age bracket, this open-end group is now accumulating the most conspicuous magnitudes. From 1970, notoriously in 2000 and further in the 2030 and 2050 projections, the d_x function in "100 and over" graphically represents sudden breaks that call for graduation and extrapolation of mortality behavior beyond age 100.

5. From Gompertz to the Bending of μ_x

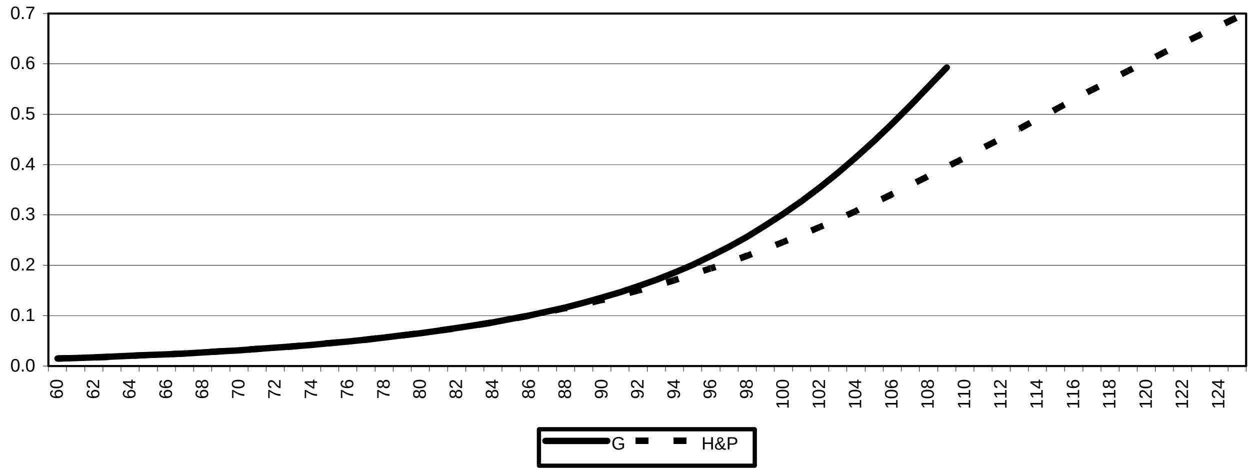
The main aim of this paper is to propose extrapolations of mortality behavior after age 100. It starts by looking at the pattern followed by q_x from age k to age 99, when k is the right side mode of d_x. For both male and female, estimates of q_x follow the well-known and traditional Gompertz (G) model. Correlation coefficients between age and mortality rates show values practically equal to 1. This kind of adjustment close to perfection is a clear indication that mortality has been already adjusted under that pattern (Gavrilov & Gavrilova, 2002). In trying to provide extrapolations to ages beyond 100, the first idea is to merely keep the G model. Such a suggestion and resulting extrapolations require discussion about their meaning and restrictions.

The first point is to contemplate that the experiences in mortality measurement in developed countries have clearly shown that the G law does not match the actual mortality rates in oldest ages. In fact it overestimates them, and therefore actual survivorship is greater (Thatcher, Kanisto & Vaupel, 1998; Olshansky, 1998; Vallin et Berlinger, 2002). The question concerns why mortality of the oldest-old is lower than the pattern generated by G. Several reasons have been proposed. An explanation centers on the selectivity of those who reach those extraordinary ages combined with the heterogeneity obtained when longer periods of observation of up to 10 years are used in order to get a sample size large enough to estimate reliable mortality rates (Perls, 1995). This procedure generates a mixture of different circumstances through time with consequences for mortality estimates (Yue, 2002).

In another discussion it is also believed that there is an influence of social and economic development along with overprotection granted to the elderly (Robine, 2000). Similarly, because of medical advances and interventions against sickness and death, greater survivorship is attained beyond what would normally happen, thus helping people to live *manufactured time* (Olshansky & Carnes, 2001). In any case, these differences between G pattern and actual mortality in advanced ages have been documented in developed societies, although they have not been fine-tuned, and explanations are not yet fully substantiated. Other considerations about selectivity of the surviving elderly show a strong relationship between health quality and the socioeconomic environment during the first stages of life, with mortality, health and well-being during adult and elderly life (Hayward & Gorman, 2001; Stone, 2000). This is an issue that has also being documented for Mexico (Ruiz-Pantoja, 2004).

The issue now is to introduce a bending on the mortality pattern for the oldest-old. Background research shows several methods and results. A clarifying work comes in a monograph by Thatcher, Kanisto & Vaupel (1998) where they compare G with models by Weibull, Kanisto, Heligman & Pollard (H&P), as well as quadratic and logistic regressions. In a consideration of data available and the meaning of this kind of adjustment, we apply H&P after age 60 under the expression $q_x = (a*\exp(b*x))/(1 + (a*\exp(b*x)))$. The resulting gap from the G model is not too wide, which keep us on the cautious side. Graph 2 shows the adjustment for mortality males in the year 2000.

Graph 2
qx ; men 60+ ; Gompertz vs Heligman & Pollard. Mexico, 2000



Life tables were extended beyond age 100 until l_x reaches zero using the two variants, G and H&P.

In Table 2 there is a summary of the differences between the two models in terms of longevity and life expectancies.

TABLE 2

Life Expectancies, Males, Gompertz vs. H&P. Mexico, 2000.			
	Gompertz	H&P	H&P/Gomp
60	20.2	20.3	100.4
70	13.8	13.9	100.8
80	8.7	8.8	102.0
90	4.9	5.3	107.7
100	2.4	3.1	128.6

A first feature is that variations in life expectancies are nil for the young and adult ages. The difference between G and H&P at age 60 is just 20.2 compared with 20.3, which is less than 0.5 percent. At age 80 the figures are 8.7 and 8.8, with a relative difference of 2 percent. It is not until age 100 (at 2.4 and 3.1) that life expectancies yield a 30 percent increment.

6. Compression of Mortality at Oldest Ages

Table 3 shows the median age at death and the interquartile range (IQR) (Wilmoth & Horiuchi, 1999) in life tables in selected years between 1930 and 2000, including projections to 2030 and 2050.

TABLE 3

Quartiles and Interquartile Range of d_x. Mexico, 2030-2050

	Men				Women			
	I	**II**	**III**	**IQR**	**I**	**II**	**III**	**IQR**
1930	2	35	63	61	3	37	65	62
1950	20	57	74	54	25	62	76	51
1970	48	69	80	32	55	72	82	27
2000	65	78	87	22	71	81	90	19
2030	73	83	92	19	77	86	94	17
2050	75	85	93	18	79	88	95	16

Figures are for men and women, and they constitute indicators about changes in survival and the compression of mortality at older ages. During the first half of the 20th century the median quickly increased. In 1930, the median was 35 for males and 37 for females, reaching 78 and 81 by 2000. With smaller increases in the future, medians are expected to be 85 and 88 by 2050. The change of median age at death is a numerical perception of population survival and aging. On the other hand, the IQR provides a measure of mortality compression. IQR has decreased at the same time as the median has increased. In 1930 it was 61 for male and 62 for female, dropping to 32 and 37 in 2000, respectively. In this trend the IQR is expected to decrease at a lower pace, estimating that it will reach the values of 18 and 17 by 2050.

Both medians and IQR are numbers that describe the age distribution at death throughout the full range of ages. Thus the figures from 1930, with low medians and high IQR, reflect high mortality, especially in regard to infant mortality. But as demographics and the health-entangled transition progress, the first traces of survival rectangularization and the shift of mortality toward adult and older ages emerges. Thus it becomes important to observe the forms and levels in mortality of the elderly population.

The distribution of the d_x is bimodal.[5] The leftmost mode of the past reflects the newly born's high risk of death; the present and future mode at the right side comes with the aging of population. For a single year both modes are linked since they are dealing with the same age at death structure. One of the indicators that depicts better the compression of mortality around the right-side mode is the *smallest interval of ages adding up 50 percent of the d_x values*. This is the C50 parameter by Vanio Kanisto (Kanisto, 2000).[6] Unlike IQR, which is constructed based on the full range of ages, C50 is composed only with the ages at death closer to the right mode. This parameter has been used to measure the degree and rhythm of mortality compression in several key publications covering the subject of mortality in old age (Meslé & Vallin, 2003; Horiuchi, 2002; Robine & Saito, 2002; Vallin & Berlinger, 2002). C50, the right modes and the corresponding frequencies appear on Table 4.

TABLE 4

d_x mode and Kanisto C50. Mexico, 1930-2050						
	Men			Women		
Año	mode	d_x	C50	mode	d_x	C50
1930	71	1,179	51.2	71	1,292	49.4
1950	74	1,749	35.7	76	1,996	30.7
1970	77	2,274	25.2	79	2,630	21.7
2000	81	2,652	19.7	84	3,174	17.2
2030	84	3,011	17.7	87	3,552	15.4
2050	86	3,120	16.5	89	3,729	14.7

In these figures, we can see the increase in time of the mode of d_x and its relationship with C50. In 1930, the modal age at death was 71 years for both sexes, and 50 percent of deaths around this mode occurred in a 50-year age range. In 1970, the mode reached 77 years for males and 79 for females, with C50 equal to 25.2 and 21.7, respectively. The mode increased to 81 and 84 by 2000, and C50 did it to 19.7 and 17.2. By 2050 it is assumed a likely mode of 86 and 89, with a C50 of 16.5 and 14.7 years.

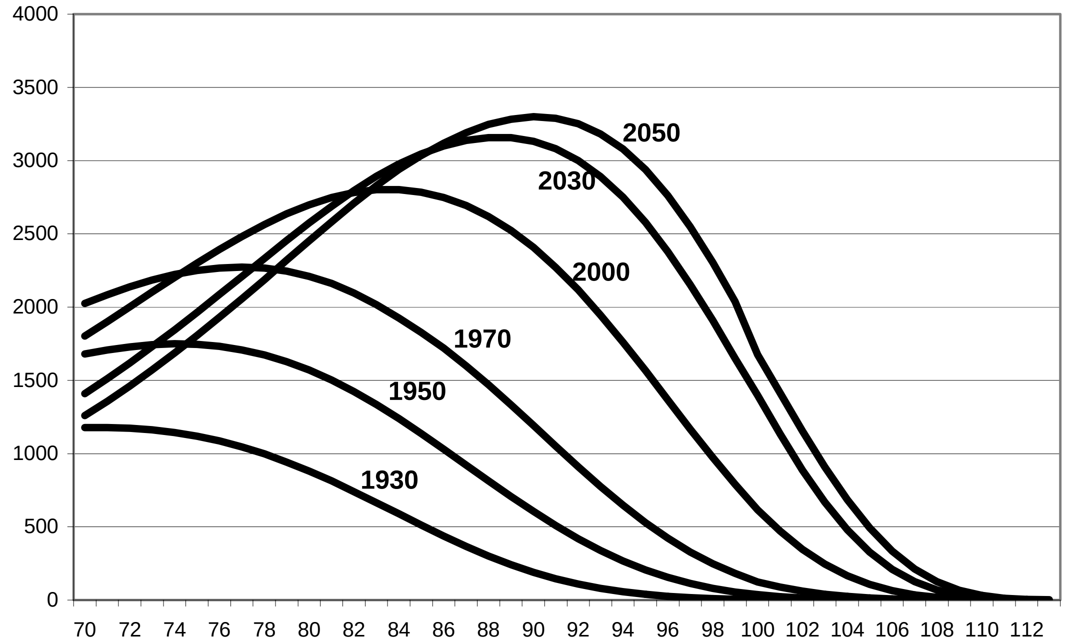
7. The Normality of d_x at the Left Side of the Mode

d_x values for women 70 and over and their dynamics through time are shown in Graph 3. A similar graph results for males. Mortality around the mode illustrates concepts that have been remarked, including mode increases and higher density of

[5] In a strict sense, we should also consider the modal value produced in young ages of the male population because of accidents and violence.
[6] To calculate the C50, we take into account the values of d_x closer to the mode, place them in a decreasing order and then accumulate them until we reach 50 percent of the radix l_0 of the mortality table.

deaths around the mode. An important feature comparable to other experiences is that values of d_x at the right side of the mode resemble the shape of a normal distribution (Fries, 1980; Wilmoth, 1997).

Graph 3
dx in women 70+ ; 1930-2050



This "right-hand side of the d_x curve" assumes the mode as the mean of the normal distribution. A topic then is the use of the standard deviation as another measure of the mortality compression, although it is hypothetical and not as specific as C50. Means, standard deviations and confidence intervals compose Table 5.

TABLE 5

Projections of d_x Mean and Standard Deviation Under the Normal Distribution. Estimates of Maximum Life Span. Mexico, 2000, 2030, 2050.								
	Men				Women			
	μ	σ	$\mu + 2\sigma$	$\mu + 3\sigma$	μ	σ	$\mu + 2\sigma$	$\mu + 3\sigma$
1930	71	9.6	90.1	99.7	71	9.6	90.3	99.9
1950	74	9.9	93.8	103.8	76	9.1	94.3	103.4
1970	77	9.8	96.6	106.4	79	9.0	97.0	105.9
2000	81	10.04	101.1	111.1	84	9.29	102.6	111.9
2030	84	9.26	102.5	111.8	87	8.33	103.5	112.0
2050	85	8.99	103.0	112.0	89	7.72	104.4	112.2

Assumptions of normality allow propositions to estimate *maximum longevity*. The approach is that confidence intervals to the right side of the mean estimate the probability of surviving to extremely advanced ages. By applying the method to past experiences and future expectations, we get approximations of what might have happened in the past and what can be expected in the future. These procedures are being applied to compare longevity among different species, including human beings (Wilmoth, 1997; Cheung et al, 2003).

When considering two standard deviations, 0.02275 is the probability of a likely survival of men and women beyond 90 years in 1930. Such conditions improved to be 97 years in 1970, were around 102 in 2000 and are projected to be 104 by the middle of the century. For three standard deviations the probability is a very low 0.00135, but it is not zero, thus suggesting a number for a possible *maximum life span*. That limit was 100 in 1930, 107 in 1970 and 111 in 2000. Projections do not advance too much, and figures are around 112 up to 2050.

8. An Example on Annuities Calculation

One of the impacts of improvements on mortality and longevity that is of high interest to social security and actuarial practices is the pricing of annuities. There are two main inputs for an annuity valuation: the life table and the rate of interest. To estimate lump sums to finance life pensions in Mexico, official mortality is derived from the *Mexican Social Security Experience 1997* (EMSS 1997). There is a life table for men (H) and another for women (M).[7] Table 6 makes a comparison of annuities valuation for men between the currently used EMSS-H 1997, the Gompertz extension of CONAPO's life table 2005, the H&P variant for 2005 and the use of the H&P following mortality dynamics for the 2005 cohort. The rate of interest was fixed to 3.5 percent.[8]

[7] EMSS-H stands for *Experiencia Mexicana del Seguro Social-Hombres* (men). Likewise for EMSS-M for women.
[8] Annuities calculations were made by Mauricio Arredondo and José Luis Salas from *Consultores Asociados de México*.

TABLE 6

Annuities Under Different Life Tables for Men, Ratios With EMSS-H 1997.				
	EMSS-H 1997	**CONAPO G 2005**	**H&P 2005**	**H&P Cohort 2005**
60	14.3499	14.3487	14.3700	14.6994
65	12.4111	12.6359	12.6369	12.9259
70	10.4355	10.9233	10.9610	11.1560
60	100.00	99.99	100.14	102.44
65	100.00	101.81	102.04	104.15
70	100.00	104.67	105.04	106.90
EMSS-H: Social Security Experience, men, 1997; CONAPO G: National Population Council - Gompertz; H & P: Heligman &Pollard model				

Direct and relative differences between EMSS and the alternatives life tables are not too high. This is especially true for age 60 and for CONAPO-G. Higher gaps come with age and the cohort approach using H&P adjustments.

9. Conclusions

When providing a description on mortality shapes beyond 100 and how many people can live to those extreme ages, rather than reaching conclusions, this paper proposes further questions. Some are new, and some are repetitions of queries that are still waiting for answers. It is important to reconstruct mortality of the oldest-old in the past and to find explanations for changes in survival to set up meaningful projections on population aging in Mexico. A must is to always take into account our own social and economic context.

Clearly life expectancies are increasing, but it is not an indefinite process. A question is, Which is the limit for the human race and for Mexico in particular? Fries conjectured that life expectancies would reach their limit at 85 years (Fries, 1980), while Olshansky and Carnes argue that to reach life expectancies above 90, we need to eliminate all avoidable causes of death (Olshansky and Carnes, 2001). Under present conditions 90 is a goal that is difficult to reach even for the more developed societies. There are now grounds for pointing out that life expectancy and longevity can go beyond the boundaries that are currently considered because of better hygiene practices, new therapies, techniques for replacement and repair of organs, and actions directed toward hindering the biological process of aging (Carey, 2003). A higher promise lies in genomic research.

Formulating it in a more direct way, which are the opportunities to further reduce the mortality rates, particularly for the advanced ages? We know that for Mexico a significant part requires overcoming social and economic differences. However, it is not just inherent disparities but also variations between countries. Disadvantages in other areas will mean that benefits from new knowledge and technologies will surely be experienced first in the countries that develop them. Innovations will flow later to less developed societies as long as they can afford costs that may be expensive.

In any case, research is due using better instruments to determine the maximum longevity in Mexico and the trends of life expectancies at all the ages. This is essential if we want to figure out what the future might be, not only in the long run but also in the near future, as it has been shown by actuarial, economic and social problems in pensions and health-care schemes. A crucial portion of these tasks is to enhance the quality of population statistics and to find out precisely the true number of people in the oldest-old ages and their characteristics. An important portion of these tasks will be to improve the recording and processing of the information about mortality and morbidity, bring into account mortality causes, link them with morbidity throughout the life cycle and apply methodologies intended to analyze the older and oldest-old groups specifically.

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