ON THE FUTURE MORTALITY OF ALGERIA

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Abstract. A new mortality forecasting approach is introduced that unlike the Lee-Carter Method (and its variants) is directly linked to the fundamental demographic equation, the cornerstone of demographic theory. This is an important consideration in developing accurate forecasts. Because it forecasts "years lived by age group" (${}_nL_x$), this new approach directly yields life expectancy in a future abridged period life table, which is not the case with the Lee-Carter Method and its variants. In an ex post facto evaluation using Algerian ${}_nL_x$ data by gender from the Human Life-Table Database, the new approach was found to provide accurate forecasts of ${}_nL_x$ by gender to 2021, where the forecasts were launched from 2006. A set of ${}_nL_x$ forecasts by gender for Algeria to 2038 that are launched from 2018 are then provided. The method, the results of the ex post facto evaluation, and the forecast are discussed, along with suggested next steps in evaluating this approach.

Keywords. Lee Carter Method. Hamilton-Perry Method, COVID-19, Period Life Table, Cohort Life Table

Background. Mortality Forecasting is an important activity. It is used in the preparation of population forecasts based on the cohort component (CCM) method (Smith, Tayman, and Swanson, 2013: 61-72), the development of social welfare, annuity and pension products (Lee and Miller, 2001; Booth and Tickle, 2008; Haberman and Renshaw, 2011; Huang, Maller, and Ning, 2020; Rabbi and Mazzuco, 2020; Shang, Booth, and Hyndman, 2011; Tabeau, Van Den Berg Jeths, and Heathcote, 2001) and epidemiological/health research (Andrade, Camarda, and Arolas, 2025; Swanson, Bryan, and Chow, 2020; Booth and Tickle, 2008).

The Lee-Carter approach to forecasting mortality was introduced in 1992 (Lee and Carter, 1992) and along with its refinements and variants is arguably the most widely used approach in the world (Booth and Tickle, 2008; Rabbi and Mazzuco, 2020; Basellini, Camarda, and Booth, 2023). As observed by Basellini, Camarda, and Booth (2023: 1034), it is useful to examine the Lee-Carter approach in terms of two aspects, the model and the method. The model is a functional form for age-specific mortality (age-specific death rates, ASDRs) and the method consists of a series of steps to estimate the model and fit a time series model to the time index, along with specific adjustment and estimation procedures. Both the model and the method are essentially mathematical fitting procedures and have no direct relationship to the dynamics of population change and the components of those change, one of which is obviously mortality. Moreover, in order to generate a forecast of life expectancy and a corresponding life table, the Lee-Carter Method and its variants require that the ASDRs be turned into a life table (e.g., Fergany's method (Fergany, 1971) and the Keyfitz-Frauenthal method (Kintner, 2004: 314-315).

This paper introduces a new method of mortality forecasting by showing that a population projection method based on the Hamilton-Perry approach ("H-P," Baker et al., 2017) can be used to generate "years lived" by age ($_nL_x$) and which also includes Total years lived (T_0) and life expectancy at birth (e_0) as found in an abridged period life table. From the perspective of formal demography, this is a forecast of the age distribution and size of the stationary population associated with the mortality and the age structure of a given population (see, e.g., Ryder, 1975; Rao and Carey, 2015).

The method is evaluated using a ex post facto approach, following which, ${}_nL_x$ forecasts for 2028, 2033, and 2038 are provided. Unlike the Lee-Carter method and its corresponding "principal components" variants (Booth and Tickle, 2008; Lee and Carter, 1992; Lee and Miller, 2001; Shang, Booth, and Hyndman, 2011) this approach, given three major constraints (described later), links the forecast to the fundamental demographic equation, the cornerstone of demographic theory. In addition to being a potential contribution to formal demography, this is an important consideration in developing accurate forecasts (Swanson, et al. 2023). Also, unlike the Lee-Carter method and its variants, this new approach directly yields life expectancy and a corresponding future life table because it directly forecasts "years lived" by age (${}_nL_x$).

The ex post facto evaluation of the accuracy of the method is conducted in the form of a case study using Algerian ${}_nL_x$ data by gender for the period 2001 to 2021, as found at the Human Life-Table Database "(HLD," https://www.lifetable.de/), and an example set of forecasts (to 2038) launched from currently available HLD ${}_nL_x$ data by gender is provided for Algeria.

Data. Algeria was selected for this case study mainly for two reasons. First, HLD provides annual ${}_nL_x$ data by gender over a period of time (2001 to 2023) that is sufficient for an ex post facto evaluation as well as current ${}_nL_x$ data by gender that can be used to forecast ${}_nL_x$. Second, it represents the UN region, "Africa," where mortality and other demographic data are not as available and of the same quality as countries in the UN's "Europe" region. To be sure, we do not present Algeria as representative of the whole of the "Africa" region. However, it is likely representative of countries in this region that are not sub-Saharan (i.e., Morocco, Tunisia, Libya, and Egypt).

While the HLD ${}_nLx$ data have a terminal open-ended age group of 85+ from 2010 to 2023, the ${}_nL_x$ values from 2001 to 2009 have a terminal open-ended age group of 80+. Given this, 80+ is used as the terminal open-ended age group in this paper.

Method. The Hamilton-Perry (H-P) method (Baker et al., 2017) is employed, which computes cohort change ratios (CCRs) using two counts of the age-structure ($_nL_x$) in question, typically five or ten years apart, which directly capture age-specific population dynamics. Before turning to a discussion of the approach used here (which is followed by a description of the input data and the projection results), it is helpful to note that the H-P method is algebraically equivalent to the fundamental demographic equation and therefore grounded in demographic theory (Baker et al., 2017: 251-252),. Barring unforeseeable catastrophes and other events that have very low probabilities of occurring (Taleb, 2010), as noted earlier, the closer one comes to having accurate data embedded in a method that is grounded in demographic theory, the more accurate a population projection method will likely be (Swanson et al., 2023), a dictum that one could reasonably expect to apply to forecasting $_nL_x$.

There are three *components of change* in a population: mortality, fertility, and migration. The overall growth or decline of a population is determined by the interplay among these three components. The exact nature of this interplay can be formalized in the *fundamental demographic equation*:

$$P_l - P_b = B - D + IM - OM, \qquad [1]$$

Where P_l is the population at the end of the time period; P_b is the population at the beginning of the time period; and B, D, IM, and OM are the number of births, deaths, in-migrants, and out-migrants during the time period, respectively. The difference between the number of births and the number of deaths is called *natural change* (B – D); it represents population growth coming from within the population itself. It may be either positive or negative, depending on whether births exceed deaths or deaths exceed births. The difference between the number of in-migrants and the number of out-migrants is called *net migration* (IM – OM); it represents population growth coming from the movement of people into and out of the area. It may be either positive or negative, depending on whether in-migrants exceed out-migrants or out-migrants exceed in-migrants. In cases where IM and OM do not occur (e.g., the world as a whole, the stationary population that is found in a life table), these elements can be omitted from the fundamental population equation.

The fundamental demographic equation can also be extended to apply to age groups, age-gender groups, and age-gender-race groups, as well as age-gender-ethnicity groups. This type of extension forms the logical basis of the equation and can be used to project a population into the future by age, age and gender, or by age, gender, and race. Once launched, these components (which are frequently modified as the projection moves into the future based on assumptions about their direction) are applied to the resulting age-gender structure at each cycle of the projection. In terms of ${}_nL_x$ there is no migration, which eliminates the need for this component in forecasting ${}_nL_x$.

The Hamilton-Perry Method of Population Projection. The Hamilton-Perry (H-P) method (Baker et al., 2017: 251-252) conforms to the fundamental population equation and is algebraically equivalent to the CCM (Baker et al., 2017: 251-252) but it does not apply the separate components of population change to the age structure at the launch year. Instead, it computes cohort change ratios (CCRs) using two counts of the age-structure in question, typically five or ten years apart, which directly capture mortality and migration. The fertility component uses a "child-adult ratio" from the most recent age structure data or a "child-woman ratio" for a projection by gender. It is well- suited for generating a projection of a population: The forecast is relatively easy to calculate and meets several important criteria used by demographers who routinely generate forecasts, including utility (Tayman and Swanson, 1996) as well as face validity, plausibility, production cost, timeliness, ease of application and ease of explanation (Smith, Tayman, and Swanson, 2013: 302-315). Stated another way, per the framework found in Swanson et al. (2023): (1) It corresponds to the dynamics by which a population moves forward in time; (2) there is information available relevant to these dynamics; (3) the time and resources needed to assemble relevant information and generate a projection are minimal; and (4) the information needed from the projection is generated by the H-P method.

The H-P method moves a population by age (and gender) from time t to time t+k using CCRs computed from data in the two most recent data points (e.g., censuses or estimates). It consists of two steps. The first uses existing data to develop CCRs, and the second applies the CCRs to the cohorts of the launch year population to move them into the future. The formula for the first step, the development of a CCR, is:

$$ {}_{n}CCR_{x,i} = {}_{n}P_{x,i,t} / {}_{n}P_{x-k,i,t-k}, \qquad [2] $$

where

${}_{n}P_{x,i,t}$ is the population aged x to x+n in area i at the most recent census/estimate (t),

${}_{n}P_{x-k,i,t-k}$ is the population aged x-k to x-k+n in area i at the 2nd most recent census/estimate (t-k),

k is the number of years between the most recent census/estimate at time t for area i and the census/estimate preceding it for area i at time t-k.

The basic formula for the second step, moving the cohorts of a population into the future, is:

$$ {}_{n}P_{x+k,i,t+k} = ({}_{n}CCR_{x,i}) \times ({}_{n}P_{x,i,t}), \qquad [3] $$

where

${}_{n}P_{x+k,i,t+k}$ is the population aged x+k to x+k+n in area i at time t+k

Given the nature of the CCRs, they cannot be calculated for the youngest age group (i.e., ages 0-4 if it is a five-year projection cycle; ages 0-9 if it is a ten-year projection cycle), because this cohort came into existence after the census/estimate data collected at time t-k. To project the youngest age group, one uses the "Child-Adult Ratio" (CAR), where the number in the youngest age group at time t is divided by the number of adults at time t who are of childbearing age (e.g., 15-44). It does not require any data beyond what is available in the census/estimate sets of successive data.

The CAR equation for projecting the population aged 0-4 is:

$$\text{Population 0-4:} \quad {}_5P_{0,t+k} = ({}_5P_{0,t} / {}_{30}P_{15,t}) \times ({}_{30}P_{15,t+k}) \qquad [4]$$

where

P is the population,

t is the year of the most recent census, and

t+k is the estimation year.

In using the H-P method to forecast ${}_nL_x$ and in which the youngest age group is ${}_5L_0$ (ages 0-4, as is used in this paper), one obviously does not employ a CAR because the number of births in a life table is fixed, usually at 100,000 each year, which means that in a five year period (which corresponds to the width of abridged life table when 5 year age groups are employed up to the terminal, open-ended age group). Thus, ${}_5L_0$ is comprised of the survivors of these births. As such, one can simply take the ratio: ${}_5L_{0\ i,t}/{}_5L_{0\ i,t-k}$, or a variant thereof, as is done in this paper

Projections of the oldest open-ended age group differ slightly from the H-P projections for the age groups beyond age 10 up to the oldest open-ended age group. If, for example, the final closed age group is 75-79, with 80+ as the terminal open-ended age group, then calculations for the $CCR_{i,x+}$

require the summation of the three oldest age groups to get the population age 70+ at time t-k in a ten forecast cycle (80+ in a five year forecast cycle):

$$_{\infty}CCR_{70,i,t} = {}_{\infty}P_{80,i,t} \ / \ {}_{\infty}P_{70,i,t-k} \qquad [5]$$

The formula for estimating the population of 80+ of area i for the year t+k is:

$$_{\infty}P_{80,i,t+k} = ({}_{\infty}CCR_{70,i,t}) \times ({}_{\infty}P_{70,i,t}). \qquad [6]$$

An issue that is found in the cohort change ratio for the terminal, open-ended age group (which in this case is 80 years and over) in a projection where migration is not a component of population change is that like the equivalent probability of survival in an abridged life table, deaths are not uniformly distributed within the interval (Chiang, 1984: Lahiri, 2018; Swanson, Bryan, and Chow, 2020). This issue tends to exaggerate the length of life for those aged 80 and over in an abridged life table and in an H-P projection.

Before turning to the next issue, "constraints," it is important to note that a "Trended CCR" model was used. It was selected because in a preliminary exploration (the details of which are not reported here) two forms of the CCR model were examined, one in which the initial CCRs were kept constant and the other in which the initial CCRs were trended to the CCRs five year beyond the launch year and found the latter not only to be more accurate but also have fewer constraint violations. The trended model is described in detail in the "Evaluation" section.

Constraints. There are three major constraints in forecasting (or backcasting) $_nL_x$. They affect any forecast of $_nL_x$ based on the fundamental population equation, such as the CCR approach. First, the births (and deaths) in a life table are typically fixed at 100,000 annually. Second, $_nL_x$ cannot exceed this constraint in that it is limited to n*100,000 in a fixed width age group of n years. Third, $_nL_{x+i} \leq {}_nL_x$. Because the CCR approach (as well as the CCM approach) does not recognize these constraints, one must take care to make sure the forecast does not violate them. This is discussed in more detail in the "Evaluation" section.

Evaluation Using $_nL_x$ Data for Algeria. The evaluations utilize annual $_nL_x$ data taken from the full set for Algeria (2001 to 2023) found at HLD (https://www.lifetable.de/). The evaluations of the results were launched from 2006 using 2006/2001 CCRs trended to 2011/2006 CCRs. The model is shown in Table 1 while the accuracy evaluations are found in Tables 2 and 3.

(TABLE 1 ABOUT HERE)

As can be seen in Table 1a and Table 1.b, the "Trended CCR" model was employed for males and females, respectively. As noted earlier, it was selected because in a preliminary exploration (the details of which are not reported here) where two forms of the CCR model were examined, one in which the initial CCRs were kept constant and the other in which the initial CCRs were trended to the CCRs five year beyond the launch year and found the latter not only to be more accurate but also had fewer constraint violations. In regard to the violations found in the trended model, none occurred. Had there been then they would have been dealt with as follows, Adj $_nLx$ at time $_{t+n}$ = (0.8*$_nL_x$ at time $_t$) + (0.2*$_nL_x$ at time $_{t+n}$),. No violations of the third constraint were encountered.

(TABLE 2 ABOUT HERE)

Tables 2a and 2b through 3a and 3b show, respectively, the forecasts and accuracy statistics by gender for 2018 and 2021. In addition to showing the numeric and relative differences between the forecasted $_nL_x$ values, these tables also show the differences between the forecasted e_0 and the reported e_0 values. The summary accuracy measures for these forecasts are shown in Table 4a (males) and Table 4b (Females) and include MALPE (Mean Algebraic Percent Error), MAPE (Mean

Absolute Percent Error), and the Index of Dissimilarity Index (ID, also known as the Index of Misallocation, IOM).

MALPE provides a view of bias in that if it is negative, then, on average, the forecasted values are lower than the reported values while MAPE (Swanson and Tayman, 2012: 268-270) shows the mean percent difference between the forecasted and reported values regardless of whether or not the forecasts were too high or too low. ID measures the extent that the forecasted values by age differ from the reported values by age. It is interpreted as the percent of the forecasted values by age that would have to be re-distributed in order to match the reported values by age (Swanson and Tayman, 2012: 273). In assessing these measures of error, guidelines found in Smith, Tayman, and Swanson (2013: 348-352) and Swanson and Tayman, (2012 were used: 281-286) and define substantive errors as at least +-5% but less than +-10% and extreme errors (outliers) as being +-10% or more,

As seen in Tables 4a and 4b, all of the ID measures are well below 5% as are the MALPE and MAPE values and the relative differences in e_0. They are all positive, which means that the method is over-forecasting ${}_nL_x$ on average. However, given this, the results suggest that the method is capable of producing accurate forecasts of ${}_nL_x$.

Extreme errors (outliers) are neither summarized in Table 4 nor shown elsewhere but it can be reported that there are only two among the 18 age groups across the two evaluation points. Both of them occur for age 80+ in 2021. For males, the relative difference between the forecasted ${}_\infty L_{80}$ and the reported value in 2021 is 51% (Table 3a); for females, it is 35.9% (Table 3b). While much higher than the corresponding differences found in 2016, they are consistent in that the differences between forecasted ${}_\infty L_{80}$ and the reported ${}_\infty L_{80}$ are much higher than those for the other age groups. In addition, 2021 was a year of peak deaths in many parts of the world during the Covid-19 pandemic and the elderly were hit hard. In this respect, Algeria is no exception (Bentout et al., 2021; Johns Hopkins University, 2025). So, it is not surprising that this “Black Swan” event (Taleb, 2010) led to extreme over-forecasting errors among those 80+ in both genders.

(TABLE 3 ABOUT HERE)

As seen in tables 2 and 3 both of the two constraints are satisfied for all age groups across both genders in the 2016 and 2021 forecasts. Keeping in mind that Swanson and Tayman (2012: 275) point out that it is not generally possible to produce a population estimate for which all error criteria are simultaneously minimized, the evaluation suggests that the method is slightly biased toward over-forecasting ${}_nL_x$ but is, nonetheless, capable of producing forecasts that are sufficiently accurate that the method should be considered for use. This is with the proviso that evaluations of its performance should also continue, both in terms of populations that have mortality patterns similar to Algeria’s over the case study period and in terms of population that have different mortality patterns.

An Example Forecast for Algeria. Because the evaluation data cover a 20 year forecast horizon from the launch year of 2006 (with the launch using 2006/2001 CCRs trended to 2011/2006 CCRs to forecast ${}_nL_x$ for 2011, 2016, and 2021) , the same horizon is used for the example forecast, which is launched from the most recent data (2018) available in HLD. The result is a forecast launched from 2018 (using 2018/2013 CCRs trended to 2023/2018 CCRs to forecast ${}_nL_x$ for 2028, 2033, and 2038). The model for males is found in Table 5a and for females, Table 5b. The ${}_nL_x$ forecasts generated by these models by gender, respectively in tables 6a, 7a, and 8a (males) and 6b, 7b, and 8b (females). No violations of constraints 2 (${}_nL_x < 5*100{,}000$ in a fixed width age group of 5 years) and 3 (${}_nL_{x+i} \leq {}_nL_x$) are found in these forecasts.

The e_0 values found in tables 6,7, and 8 increase monotonically from 2028 to 2033 to 2038, respectively, for both genders, with , as would be expected females consistently having higher e_0 values than males. However, the increase is not dramatic, especially for males, for whom e_0 goes from 77.19 in 2028, to 77.46 in 2033, to 7.61 in 2038. The increase for females is from 82.29 in 2028 to 84.01 in 2033, to 84.42 in 2038. Part of the reason for the slow rate of increase is due to the fact that the 2018/2013 CCRs are trended to 2021/2018, which, while remaining consistent with the ex post facto evaluation forecasts, means they are affected by the increased mortality due to COVID-19 found in 2021.

(TABLES 4, 5, 6, AND 7 ABOUT HERE)

Discussion. As observed by Tóth (2021: 129), the efficiency of a given mortality forecasting approach largely depends on the character of the given time series it employs. That is, the historical data, which explains variation in the usefulness of models with different demographic backgrounds. This observation applies not only to Algeria but to all of the other $_nL_x$ data sets found in HLD (https://www.lifetable.de/), which represent 142 countries. As a member of the UN's "Africa" region of the world, Algeria can be viewed as a sample of this region, especially the area above the sub-Saharan line, one that is representative in terms of relatively high fertility and mortality and with net out-migration. Given the results of the ex post facto evaluation, the results suggest that the method will likely work in countries that generally share its characteristics. It is an open question whether it will work in countries that have different demographic backgrounds

Constructing CCRs from two consecutive period life tables implies that the two life tables also represent cohort mortality. For example, in the 2006 and 2001 period life tables used to construct the CCRs for the evaluation, $_5L_{24}$ in 2006 is viewed as the cohort that five years earlier was five years younger, $_5L_{20}$. Given this, none of the CCRs beyond $_5L_0$ should exceed 1.00. However, as can be seen in tables 1a and 1b, the majority of CCRs slightly exceed 1.00. To a lesser extent this also is seen in tables 5a and 5b. Because period life tables are not constructed with cohorts in mind, these “anomalies” can occur when two successive period life tables are viewed in terms of sets of cohorts. This serves to remind us that the CCRs generated from two successive period life tables, which is the case in this approach to forecasting ${}_{n}L_{x}$, the CCRs represent approximations of the mortality experience of different sets of cohorts (e.g., in the period life table at time = t+5, ${}_{5}L_{10}$ is part of the cohort ${}_{5}L_{0}$ found at time = t-5 as is ${}_{5}L_{5}$ found in the period life table at time = t; whereas in the period life table at time = t+5, ${}_{5}L_{15}$ is part of the cohort ${}_{5}L_{0}$ found at time = t-10 as is ${}_{5}L_{10}$ found in the period life table at time = t; and so on). If the approximation are close, such that the entire set of CCR approximates the mortality experience of these sets of cohorts, as apparently is the case with the CCRs in tables 1a and 1b (and for which this is the expectation in regard to table 5a and 5b), the approach should work reasonably well over a 15 to 20 year period, as our evaluation indicates. If they do not, one can expect more violations of the constraints, which would require more adjustments than we needed in order to work or lead one to the decision not to use this approach if the violations are extensive and pronounced.

In regard to the constraints and the simple adjustment used to overcome violations of these constraints, it may be the case that they may not work as well in other populations, especially those with different demographic backgrounds. As suggested earlier, a useful starting point for the resolution of violations is found in the “floors and ceilings” discussion found in Swanson Schlottman, and Schmidt (2010). And, of course, there are the many related tools found online that can be used for the purpose of overcoming these violations, such as those found at *DemoTools* (https://timriffe.github.io/DemoTools/index.html) and the *Applied Demography Toolbox* (https://applieddemogtoolbox.github.io/).

Unlike the Lee-Carter Method (and its variants) the new method is directly linked to the fundamental demographic equation, the cornerstone of demographic theory, an important consideration in developing accurate forecasts (Swanson et al, 2024). Because it forecasts “years lived,” this new approach directly yields “total years lived” (T_0) via the summation of $_nL_x$ values from 80+ back to age group 0-4. When T_0 is divided by 100,000, life expectancy at birth (e_0) is provided. Moreover, by summing back to age x, life expectancy at that age (e_x) also is found. This is not the case with the Lee-Carter Method and its variants, which would require life table construction from the forecasted ASDR’s (e.g., Fergany’s method (Fergany, 1971) and the Keyfitz-Frauenthal method (Kintner, 2004: 314-315)) in order to generate $_nL_x$.

As noted at the outset, from the perspective of formal demography the CCR approach to forecasting $_nL_x$ is a means of forecasting the age structure and size of the stationary population that is associated with a given population (at a given point in time). As such, it can be viewed as a contribution to formal demography similar to contribution that demonstrated the CCR approach can used to take a given population to stability (Swanson, 2024; Swanson, Baker, and Tedrow, 2016).

Some may argue that the use of a simple forecasting method, such as which is employed here, lacks “real world” predictive ability. In reply to this argument, Green and Armstrong (2015) find that while no evidence shows complexity improves accuracy, complexity remains popular among (1) researchers because they are rewarded for publishing in highly ranked journals, which favor complexity; (2) methodologists, because complex methods can be used to provide information that supports decision makers' plans; and (3) clients, who may be reassured by incomprehensibility. In regard to the simple forecasting method being “extrapolative,” it is worthwhile to note that virtually all “objective” forecasting methods not only include elements of judgement, but are in essence extrapolative and based on historical data, to include ARIMA (Box and Jenkins, 1976; Pflaumer, 1992), the Cohort Component Method (Smith, Tayman, and Swanson, 2013: 45-50); structural models (Smith, Tayman, and Swanson, 2013: 215-238), the Lee-Carter mortality forecasting method (Lee and Carter, 1992; Basellini, Camarda, and Booth, 2023), and even what many would consider to be a "subjective" method – The Delphi Technique (Dalkey, 1969). Moreover, while forecasting comes with uncertainty, as Anatole Romaniuc (2010: 14) observed, "Uncertainty should not be a deterrent to exploring the future."

In terms of future research, it would be useful to conduct the same type of evaluation for different countries. In terms of either the Human Mortality Database (41 countries) or the Human Life-Table Database (142 countries) this could be done by region of the world (as specified by the United Nations, there are five, Africa, Americas, Asia, Europe, and Oceania). Among HLD's 142 countries, there is a fair contingent from Africa, to include among others, Botswana, Cameroon, Egypt, Gambia, Ghana, South Africa, Tanzania and Zambia.. Examples for other UN regions include Lithuania, a member of the UN's Europe region of world; Indonesia, a member of the UN's "Oceania" region of the world, Argentina, a member of the UN's "Americas" region of the world, and Japan, a member of the UN's "Asia" region of the world.

In addition to further examination of the issues underlying the constraint violations, another area for future research is to conduct evaluations similar to those employed here in terms of ${}_{n}L_{x}$ by characteristics beyond gender. Many life tables are by gender and some other characteristic (race, ethnicity, national origin) and this would be a natural area for the next step in future research.

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Table 1a. Algerian Male CCR Model using 2006/2001 CCRs Trended to 2011/2006 CCRs

	${}_{n}L_{x}$	${}_{n}L_{x}$	${}_{n}L_{x}$	2006/2001	2011/2006	TREND
AGE	2001	2006	2011	CCR	CCR	IN CCR
0-4	472,209	485,091	487,094	1.027280293	1.004129122	0.977463628
5-9	468,385	482,828	485,268	1.022487924	1.00036488	0.978363516
10-14	466,520	481,512	484,165	1.02802609	1.002769102	0.975431569
15-19	464,490	480,022	482,802	1.028941953	1.002679061	0.974475827
20-24	461,542	477,928	480,892	1.028930655	1.001812417	0.973644251
25-29	457,830	475,265	478,522	1.029732939	1.001242865	0.972332561
30-34	453,708	472,170	475,820	1.03132167	1.00116777	0.970761886
35-39	449,110	468,502	472,750	1.032606875	1.001228371	0.969612343
40-44	443,372	463,902	468,912	1.032936252	1.00087513	0.96896118
45-49	435,675	457,822	463,408	1.032591142	0.99893512	0.967406245
50-54	424,678	448,925	455,200	1.030412578	0.994272883	0.964926967
55-59	409,130	435,360	442,632	1.025153175	0.985982068	0.961789996
60-64	385,358	415,350	423,478	1.015202992	0.972707644	0.958141034
65-69	350,970	387,008	395,915	1.004281733	0.953208138	0.949144156
70-74	303,422	346,288	355,960	0.986659828	0.919774268	0.932210111
75-79	238,248	288,718	298,398	0.95153944	0.861704708	0.905590112
80+	220,533	313,027	378,034	0.682301577	0.628229566	0.920750569
T_0	6,905,180	7,379,718	7,529,250			
e_0	69.05	73.80	75.29			

Table 1b. Algerian Female CCR Model using 2006/2001 CCRs Trended to 2011/2006 CCRs

	$_nL_x$	$_nL_x$	$_nL_x$	2006/2001	2011/2006	TREND
AGE	2001	2006	2011	CCR	CCR	IN CCR
0-4	475,079	486,540	488,536	1.024124409	1.004102438	0.980449669
5-9	471,832	484,492	486,892	1.019813547	1.000723476	0.981280822
10-14	470,450	483,438	486,012	1.024597738	1.003137307	0.979054774
15-19	469,140	482,490	485,130	1.025592518	1.003499932	0.97845871
20-24	467,402	481,308	484,098	1.025936821	1.003332712	0.977967348
25-29	465,308	479,745	482,832	1.026407675	1.003166372	0.977356655
30-34	462,698	477,680	481,072	1.02658884	1.002766053	0.976794227
35-39	459,028	474,905	478,568	1.026382219	1.001858985	0.976107113
40-44	453,868	470,942	475,080	1.025954844	1.000368495	0.97506094
45-49	446,958	465,392	470,018	1.025390642	0.998037975	0.973324637
50-54	437,565	457,538	462,785	1.023671128	0.994398271	0.971404041
55-59	425,648	446,560	452,320	1.020556946	0.988595483	0.968682333
60-64	407,272	430,788	436,845	1.012075706	0.978244805	0.966572757
65-69	378,865	406,872	414,320	0.999017855	0.96177238	0.962717908
70-74	337,248	370,198	379,835	0.977123778	0.933549126	0.955405188
75-79	275,842	315,380	324,582	0.93515751	0.876779453	0.937574092
80+	275,128	348,212	449,611	0.631998112	0.677541321	1.072062253
T_0	7,179,331	7,562,480	7,738,536			
e_0	71.79	75.62	77.39			

Table 2a. 2016 Algerian Male $_nL_x$ Forecast

	TRENDED CCR	TRENDED CCR					
	EXPECTED, WITH $_nL_x$	EXPECTED	ACTUAL				
	CONSTRAINED TO < 500,000	$_nL_x$	$_nL_x$	DIFFERENCE			INDEX OF
AGE	2016	2016	2016	NUMERIC	PCT	ABS PCT	DISSIMILARITY
0-4	489,105	489,105	487,675	1,430	0.00293	0.00293	0.00004
5-9	487,272	487,272	486,108	1,164	0.00239	0.00239	0.00008
10-14	486,612	486,612	485,205	1,407	0.00290	0.00290	0.00004
15-19	485,462	485,462	483,982	1,480	0.00306	0.00306	0.00003
20-24	483,677	483,677	482,085	1,592	0.00330	0.00330	0.00002
25-29	481,490	481,490	479,898	1,592	0.00332	0.00332	0.00002
30-34	479,081	479,081	477,612	1,469	0.00308	0.00308	0.00003
35-39	476,404	476,404	474,952	1,452	0.00306	0.00306	0.00003
40-44	473,164	473,164	471,530	1,634	0.00346	0.00346	0.00001
45-49	468,413	468,413	466,682	1,731	0.00371	0.00371	0.00001
50-54	460,754	460,754	459,250	1,504	0.00327	0.00327	0.00002
55-59	448,819	448,819	447,940	879	0.00196	0.00196	0.00009
60-64	430,552	430,552	430,010	542	0.00126	0.00126	0.00013
65-69	403,663	403,663	403,202	461	0.00114	0.00114	0.00013
70-74	364,152	364,152	365,312	-1,160	-0.00317	0.00317	0.00032
75-79	306,732	306,732	312,170	-5,438	-0.01742	0.01742	0.00086
80+	424,955	424,955	409,394	15,561	0.03801	0.03801	0.00184
T_0	7,650,306	7,650,306	7,623,007				
e_0	76.50	76.50	76.23		0.33%	0.57%	0.19%
					MALPE	MAPE	ID

Table 2b. 2016 Algerian Female $_nL_x$ Forecast

	TRENDED CCR	TRENDED CCR					
	EXPECTED, WITH $_nL_x$	EXPECTED	ACTUAL				
	CONSTRAINED TO < 500,000	$_nL_x$	$_nL_x$	DIFFERENCE			INDEX OF
AGE	2016	2016	2016	NUMERIC	PCT	ABS PCT	DISSIMILARITY
0-4	490,540	490,540	489,137	1,403	0.00287	0.00287	0.00033
5-9	488,889	488,889	487,748	1,141	0.00234	0.00234	0.00036
10-14	488,420	488,420	486,932	1,488	0.00305	0.00305	0.00031
15-19	487,713	487,713	486,042	1,671	0.00344	0.00344	0.00029
20-24	486,747	486,747	484,975	1,772	0.00365	0.00365	0.00027
25-29	485,631	485,631	483,730	1,901	0.00393	0.00393	0.00026
30-34	484,168	484,168	482,098	2,070	0.00429	0.00429	0.00023
35-39	481,966	481,966	479,815	2,151	0.00448	0.00448	0.00022
40-44	478,744	478,744	476,562	2,182	0.00458	0.00458	0.00021
45-49	474,148	474,148	471,858	2,290	0.00485	0.00485	0.00020
50-54	467,385	467,385	465,108	2,277	0.00490	0.00490	0.00019
55-59	457,507	457,507	455,435	2,072	0.00455	0.00455	0.00021
60-64	442,480	442,480	440,888	1,592	0.00361	0.00361	0.00025
65-69	420,145	420,145	419,230	915	0.00218	0.00218	0.00032
70-74	386,788	386,788	387,492	-704	-0.00182	0.00182	0.00049
75-79	333,032	333,032	337,622	-4,590	-0.01360	0.01360	0.00093
80+	524,548	524,548	480,739	43,809	0.09113	0.09113	0.00507
T_0	7,878,851	7,878,851	7,815,411				
e_0	78.79	78.79	78.15		0.76%	0.94%	0.51%
					MALPE	MAPE	ID

Table 3a. 2021 Algerian Male $_nL_x$ Forecast

	TRENDED CCR EXPECTED, WITH $_nL_x$ CONSTRAINED TO < 500,000	TRENDED CCR EXPECTED $_nL_x$	ACTUAL $_nL_x$	DIFFERENCE			INDEX OF
AGE	2021	2021	2021	NUMERIC	PCT	ABS PCT	DISSIMILARITY
0-4	491,125	491,125	488,599	2,526	0.00517	0.00517	0.00104
5-9	487,450	487,450	487,322	128	0.00026	0.00026	0.00135
10-14	487,959	487,959	486,542	1,417	0.00291	0.00291	0.00118
15-19	486,763	486,763	485,372	1,391	0.00287	0.00287	0.00118
20-24	484,554	484,554	483,615	939	0.00194	0.00194	0.00124
25-29	482,088	482,088	481,465	623	0.00129	0.00129	0.00127
30-34	479,640	479,640	479,175	465	0.00097	0.00097	0.00129
35-39	476,990	476,990	476,575	415	0.00087	0.00087	0.00129
40-44	473,578	473,578	472,998	580	0.00123	0.00123	0.00125
45-49	467,914	467,914	467,528	386	0.00083	0.00083	0.00126
50-54	458,115	458,115	458,670	-555	-0.00121	0.00121	0.00136
55-59	442,528	442,528	444,320	-1,792	-0.00403	0.00403	0.00149
60-64	418,801	418,801	421,265	-2,464	-0.00585	0.00585	0.00151
65-69	384,775	384,775	384,830	-55	-0.00014	0.00014	0.00109
70-74	334,938	334,938	334,002	936	0.00280	0.00280	0.00082
75-79	264,313	264,313	266,025	-1,712	-0.00644	0.00644	0.00097
80+	459,667	459,667	304,683	154,984	0.50867	0.50867	0.01959
T_0	7,581,196	7,581,196	7,422,986				
e_0	75.81	75.81	74.23		3.01%	3.22%	1.96%
					MALPE	MAPE	ID

Table 3b. 2021 Algerian Female $_nL_x$ Forecast

	TRENDED CCR	TRENDED CCR					
	EXPECTED, WITH $_nL_x$	EXPECTED	ACTUAL				
	CONSTRAINED TO < 500,000	$_nL_x$	$_nL_x$	DIFFERENCE			INDEX OF
AGE	2021	2021	2021	NUMERIC	PCT	ABS PCT	DISSIMILARITY
0-4	492,553	492,553	491,326	1,227	0.00250	0.00250	0.00079
5-9	489,243	489,243	490,255	-1,012	-0.00206	0.00206	0.00107
10-14	489,952	489,952	489,592	360	0.00074	0.00074	0.00089
15-19	489,420	489,420	488,772	648	0.00133	0.00133	0.00085
20-24	488,369	488,369	487,665	704	0.00144	0.00144	0.00085
25-29	487,169	487,169	486,250	919	0.00189	0.00189	0.00082
30-34	485,507	485,507	484,538	969	0.00200	0.00200	0.00081
35-39	482,862	482,862	482,120	742	0.00154	0.00154	0.00083
40-44	478,921	478,921	478,522	399	0.00083	0.00083	0.00087
45-49	473,218	473,218	473,305	-87	-0.00018	0.00018	0.00092
50-54	464,767	464,767	465,808	-1,041	-0.00223	0.00223	0.00103
55-59	452,290	452,290	454,562	-2,272	-0.00500	0.00500	0.00116
60-64	432,853	432,853	437,145	-4,292	-0.00982	0.00982	0.00139
65-69	404,084	404,084	410,118	-6,034	-0.01471	0.01471	0.00156
70-74	361,086	361,086	369,265	-8,179	-0.02215	0.02215	0.00175
75-79	291,995	291,995	311,985	-19,990	-0.06407	0.06407	0.00315
80+	581,045	581,045	427,809	153,236	0.35819	0.35819	0.01871
T_0	7,845,333	7,845,333	7,729,037				
e_0	78.45	78.45	77.29		1.47%	2.89%	1.87%

Table 4a. Summary Measures of Error: Ex Post Facto Male ${}_nL_x$ Forecasts Launched from 2006.

YEAR	MALPE	MAPE	FORECASTED e_0	REPORTED e_0	FORECASTED - REPORTED e_0	RELATIVE DIFFERENCE IN e_0	INDEX OF DISSIMILARITY
2016	0.33%	0.57%	76.50	76.23	0.27	0.36%	0.19%
2021	3.01%	3.22%	75.81	74.23	1.58	2.13%	1.96%

Table 4b. Summary Measures of Error: Ex Post Facto Female ${}_nL_x$ Forecasts Launched from 2006.

YEAR	MALPE	MAPE	FORECASTED e_0	REPORTED e_0	FORECASTED - REPORTED e_0	RELATIVE DIFFERENCE IN e_0	INDEX OF DISSIMILARITY
2016	0.76%	0.94%	78.79	78.15	0.63	0.81%	0.51%
2021	1.47%	2.89%	78.45	77.29	1.16	1.50%	1.87%

Table 5a. Algerian Male CCR Model using 2018/2013 CCRs Trended to 2023/2018 CCRs

	$_nL_x$	$_nL_x$	$_nL_x$	2018/2013	2023/2018	TREND
AGE	2013	2018	2023	CCR	CCR	IN CCR
0-4	487,614	488,249	488,644	1.00130226	1.000809013	0.999507395
5-9	485,810	486,738	487,245	0.998203497	0.997943672	0.999739708
10-14	484,708	485,832	486,388	1.000045285	0.999280927	0.999235677
15-19	483,392	484,558	485,110	0.999690535	0.99851389	0.99882299
20-24	481,518	482,740	483,072	0.998651198	0.996933288	0.998279769
25-29	479,200	480,582	480,732	0.998056147	0.995840411	0.997779948
30-34	476,658	478,258	478,428	0.998034224	0.995517935	0.997478755
35-39	473,775	475,578	475,890	0.997734225	0.995048698	0.997308374
40-44	470,022	472,115	472,652	0.996496227	0.993847487	0.997341946
45-49	464,675	467,238	468,060	0.994076873	0.991410991	0.997318234
50-54	456,765	459,820	460,920	0.989551837	0.986477983	0.996893691
55-59	444,842	448,222	449,670	0.981296728	0.977926145	0.996565174
60-64	426,635	430,408	432,350	0.967552524	0.964588976	0.996937067
65-69	399,742	404,260	406,575	0.947554701	0.944626959	0.996910212
70-74	361,125	365,690	369,830	0.914815056	0.914832039	1.000018564
75-79	305,335	311,510	318,558	0.8626099	0.871114879	1.009859589
80+	394,863	407,207	437,328	0.581559787	0.608484285	1.046297042
T_0	7,576,679	7,629,005	7,681,452			
e_0	75.77	76.29	76.81			

Table 5b. Algerian Female CCR Model using 2018/2013 CCRs Trended to 2023/2018 CCRs

	$_nL_x$	$_nL_x$	$_nL_x$			
				2018/2013	2023/2018	TREND
AGE	2013	2018	2023	CCR	CCR	IN CCR
0-4	488,740	489,705	490,638	1.001974465	1.001905229	0.9999309
5-9	487,130	488,352	489,488	0.999206122	0.999556876	1.000351033
10-14	486,230	487,600	488,825	1.000964835	1.000968564	1.000003725
15-19	485,290	486,732	488,080	1.001032433	1.000984413	0.99995203
20-24	484,208	485,648	487,178	1.000737703	1.000916315	1.00017848
25-29	482,895	484,362	486,098	1.000318045	1.000926597	1.000608358
30-34	481,128	482,760	484,802	0.999720436	1.000908411	1.001188308
35-39	478,572	480,550	483,080	0.998798656	1.000662855	1.001866441
40-44	475,022	477,335	480,598	0.997415227	1.000099886	1.002691616
45-49	470,070	472,742	476,885	0.995200222	0.999057266	1.003875646
50-54	463,082	466,222	471,422	0.991813985	0.997207779	1.005438312
55-59	453,192	456,802	463,578	0.986438687	0.994328882	1.007998667
60-64	438,810	442,855	452,138	0.977190683	0.989789887	1.012893291
65-69	416,482	421,950	434,280	0.961577904	0.980637003	1.01982065
70-74	381,668	389,838	406,638	0.936026047	0.96371134	1.029577482
75-79	328,318	340,335	364,082	0.891704308	0.933931531	1.047355633
80+	460,761	409,630	570,831	0.519124194	0.76114352	1.466206986
T_0	7,761,598	7,763,418	8,018,641			
e_0	77.62	77.63	80.19			

Table 6a. 2028 Algerian Male $_nL_x$ Forecast

	TRENDED CCR EXPECTED, WITH $_nL_x$ CONSTRAINED TO < 500,000	TRENDED CCR EXPECTED $_nL_x$
AGE	2028	2028
0-4	489,039	489,039
5-9	487,639	487,639
10-14	486,895	486,895
15-19	485,665	485,665
20-24	483,622	483,622
25-29	481,063	481,063
30-34	478,577	478,577
35-39	476,059	476,059
40-44	472,962	472,962
45-49	468,592	468,592
50-54	461,731	461,731
55-59	450,746	450,746
60-64	433,747	433,747
65-69	408,409	408,409
70-74	371,948	371,948
75-79	322,164	322,164
80+	459,945	459,945
T_0	7,718,804	7,718,804
e_0	77.19	77.19

Table 6b. 2028 Algerian Female $_nL_x$ Forecast

	TRENDED CCR EXPECTED, WITH $_nL_x$ CONSTRAINED TO < 500,000	TRENDED CCR EXPECTED $_nL_x$
AGE	2028	2028
0-4	491,573	491,573
5-9	490,421	490,421
10-14	489,962	489,962
15-19	489,306	489,306
20-24	488,527	488,527
25-29	487,629	487,629
30-34	486,540	486,540
35-39	485,123	485,123
40-44	483,128	483,128
45-49	480,145	480,145
50-54	475,553	475,553
55-59	468,749	468,749
60-64	458,845	458,845
65-69	443,383	443,383
70-74	418,521	418,521
75-79	379,772	379,772
80+	711,603	711,603
T_0	8,228,780	8,228,780
e_0	82.29	82.29

Table 7a. 2033 Algerian Male $_nL_x$ Forecast

	TRENDED CCR	TRENDED CCR
	EXPECTED, WITH $_nL_x$	EXPECTED
	CONSTRAINED TO < 500,000	$_nL_x$
AGE	2033	2033
0-4	489,435	489,435
5-9	488,034	488,034
10-14	487,289	487,289
15-19	486,171	486,171
20-24	484,176	484,176
25-29	481,611	481,611
30-34	478,906	478,906
35-39	476,208	476,208
40-44	473,130	473,130
45-49	468,900	468,900
50-54	462,256	462,256
55-59	451,539	451,539
60-64	434,784	434,784
65-69	409,729	409,729
70-74	373,626	373,626
75-79	324,009	324,009
80+	475,901	475,901
T_0	7,745,703	7,745,703
e_0	77.46	77.46

Table 7b. 2033 Algerian Female $_nL_x$ Forecast

	TRENDED CCR	TRENDED CCR
	EXPECTED, WITH $_nL_x$	EXPECTED
	CONSTRAINED TO < 500,000	$_nL_x$
AGE	2033	2033
0-4	492,509	492,509
5-9	491,355	491,355
10-14	490,896	490,896
15-19	490,444	490,444
20-24	489,755	489,755
25-29	488,980	488,980
30-34	488,072	488,072
35-39	486,862	486,862
40-44	485,172	485,172
45-49	482,673	482,673
50-54	478,804	478,804
55-59	472,857	472,857
60-64	463,963	463,963
65-69	449,960	449,960
70-74	427,293	427,293
75-79	390,870	390,870
80+	830,693	830,693
T_0	8,401,157	8,401,157
e_0	84.01	84.01

Table 8a. 2038 Algerian Male $_nL_x$ Forecast

	TRENDED CCR EXPECTED, WITH $_nL_x$ CONSTRAINED TO < 500,000	TRENDED CCR EXPECTED $_nL_x$
AGE	2038	2038
0-4	489,831	489,831
5-9	488,429	488,429
10-14	487,683	487,683
15-19	486,564	486,564
20-24	484,680	484,680
25-29	482,162	482,162
30-34	479,452	479,452
35-39	476,535	476,535
40-44	473,278	473,278
45-49	469,066	469,066
50-54	462,559	462,559
55-59	452,052	452,052
60-64	435,549	435,549
65-69	410,709	410,709
70-74	374,833	374,833
75-79	325,471	325,471
80+	486,733	486,733
T_0	7,765,587	7,765,587
e_0	77.66	77.66

Table 8b. 2038 Algerian Female ${}_nL_x$ Forecast

	TRENDED CCR EXPECTED, WITH ${}_nL_x$ CONSTRAINED TO < 500,000	TRENDED CCR EXPECTED ${}_nL_x$
AGE	2038	2038
0-4	493,448	493,448
5-9	492,291	492,291
10-14	491,831	491,831
15-19	491,379	491,379
20-24	490,894	490,894
25-29	490,208	490,208
30-34	489,424	489,424
35-39	488,396	488,396
40-44	486,911	486,911
45-49	484,714	484,714
50-54	481,325	481,325
55-59	476,089	476,089
60-64	468,029	468,029
65-69	454,979	454,979
70-74	433,632	433,632
75-79	399,063	399,063
80+	929,784	929,784
T_0	8,542,396	8,542,396
e_0	85.42	85.42