Mortality projections

Introduccion

Mortality projections serve as a foundational pillar in population forecasting, standing alongside fertility and migration as one of the three critical variables that determine the shape of our future society. They are essential for understanding future demographic trends and planning for social services, healthcare, and economic development. They are a critically important tool for policymakers, demographers, and researchers to anticipate and respond to changes in population dynamics. The failure to accurately project mortality rates can lead to significant misallocations of resources and inadequate planning for future needs.

Within the balancing equation of demography, mortality serves as the primary metric for assessing the health and survival limits of a population. As global societies undergo a the epidemiological transition characterized by a shift from infectious diseases to chronic and age-related illness, the ability to forecast future survival patterns has become essential for understanding broader demographic trends (Omran 2005; Vaupel 2010). Consequently, mortality projections are no longer merely statistical exercises; they are vital instruments for social planning, economic forecasting, and the development of public health strategies.

For policymakers and researchers, these projections provide the quantitative foundation required to anticipate and respond to the challenges of an aging society. Specifically, accurate forecasts are critical for the solvency of national pension systems and the longterm sustainability of social security frameworks (R. D. Lee and Carter 1992; Bengtsson and Keilman 2019). In the area of public health, projections allow for the strategic allocation of resources toward geriatric care and the management of non-communicable diseases that are common in older populations (Christensen et al. 2009). Without robust data, governments risk “longevity risk” the economic threat posed by populations living significantly longer than anticipated by historical models.

The historical record demonstrates that failing to accurately project mortality can lead to severe structural consequences. For decades, official forecasts consistently underestimated the pace of mortality decline, particularly at older ages, leading to inadequate planning for healthcare infrastructure and retirement funding [Oeppen and Vaupel (2002); Booth (2006)). This historical underestimation underscores the necessity of moving beyond simple deterministic models toward modern computerized tools and stochastic frameworks.

The transition from deterministic to stochastic modeling represents a paradigm shift in the field of demographic forecasting. Historically, mortality projections relied on deterministic methods, such as the Gompertz-Makeham law of mortality or expert-led "scenario-based" variants used by institutions like the United States Social Security Administration. These older models often assumed a fixed rate of improvement or relied on subjective "high," "medium," and "low" scenarios that failed to capture the non-linear and age-specific nature of mortality decline (Booth 2006). Critically, deterministic models offer no formal measure of uncertainty; they provide a single trajectory that historically has proven to be consistently over-conservative, leading to the repeated underestimation of life expectancy gains at older ages (R. Lee and Miller 2001).

The landmark introduction of the Lee and Carter (1992) model revolutionized the field by shifting the focus from expert opinion to a data-driven, statistical framework. The Lee-Carter method employs a stochastic approach that decomposes the logarithm of age-specific death rates into three components: an average age profile, a time varying mortality index, and an age-specific response to that index. By using Singular Value Decomposition (SVD) to extract the primary trend of mortality change, the model allows the data itself to dictate the pace of decline rather than imposing arbitrary limits on survival (R. D. Lee and Carter 1992). This method has since become the "gold standard" in demography, adopted as a benchmark by the U.S. Census Bureau and the United Nations due to its robustness and its ability to accurately reflect long-term historical trends (Girosi and King 2008).

Beyond its predictive accuracy, the primary value of the Lee-Carter framework lies in its stochastic nature. Unlike deterministic models, which offer a "best guess," stochastic models treat future mortality as a random process with an associated probability distribution. By modeling the time-varying index (kt) as a stochastic time series typically a random walk with drift—researchers can generate probabilistic intervals for future life expectancy. This quantification of uncertainty is indispensable for modern risk management; it allows policymakers and actuaries to calculate "longevity risk" and the probability of extreme outcomes, such as a "95% confidence interval" for the future old-age dependency ratio (Cairns, Blake, and Dowd 2006; R. Lee 2000). In a 21st-century context, where the pace of medical innovation and the impact of global health crises are unpredictable, the ability to communicate uncertainty through these probabilistic frameworks is no longer a luxury, but a prerequisite for responsible fiscal and social planning.

Within this global context of shifting survival patterns and advancing methodology, Puerto Rico presents a particularly unique case in need of demographic analysis. The island has undergone a rapid demographic transition, characterized by a rapid population aging due to massive outmigration driven largely by the exodus of working age adults (U.S. Census Bureau 2024; Angel Matos-Moreno, Garcia, and Himes 2023).

To date, research on Puerto Rican mortality has been primarily focused on specific health outcomes. There is a robust and well documented record on research for specific topics ranging from infant mortality, diabetes, cardiovascular disease, and the impact of external causes like respiratory illness following natural disasters (Cruz-Rivera et al. 2014; Mattei et al. 2022).

While these studies provide invaluable insights into the specific health burdens of the Puerto Rican population, they treat mortality as a static or retrospective variable, rather than a dynamic future trajectory. This presents a critical gap in the literature, as policymakers and public health officials require forward looking projections to effectively plan for the island's unique demographic challenges. The rapid aging of the population, coupled with the lingering effects of natural disasters and economic instability, necessitates a comprehensive understanding of how mortality patterns will evolve in the coming decades.

This gap is particularly critical given Puerto Rico's unique socioeconomic challenges, including a shrinking tax base, significant outmigration of the working age population, and a healthcare system under increasing strain from an aging demographic. Without a general mortality projection, it is difficult for local policy makers to estimate the future old age dependency ratio or to plan for the longterm solvency of social safety nets. By applying modern computerized tools to bridge the divide between cause specific research and general demographic forecasting, this thesis seeks to provide the first comprehensive mortality projection for Puerto Rico, offering a vital resource for the island's future strategic planning.Specifically, we will generate detailed life tables and predicted age-specific death rates, which will then be benchmarked against published figures from authoritative entities such as the U.S. Census Bureau and the World Population Prospects provided by the United Nations to validate the model's accuracy and offer a vital resource for the island's future strategic planning.

The lack of precise, forward looking mortality data has already manifested in severe institutional challenges across Puerto Rico, most notably within its social safety nets and fiscal frameworks. The island's retirement systems offer a cautionary example of how demographic uncertainty can lead to systemic collapse. For decades, the mismatch between projected and actual dependency ratios, driven by a shrinking tax base and a rapidly aging population, contributed to the total exhaustion of the employees retirement system's trust funds (Abel and Deitz 2014; Cox Alomar 2019). Because policymakers lacked robust, stochastic projections to account for the accelerated pace of aging, the government was eventually forced to transition to a "Pay As You Go" or "PayGo" model. This shift has placed an enormous, immediate burden on the central budget, where pension payments now compete directly with essential services like education and public safety (LLP 2023).

In the healthcare sector, the absence of comprehensive mortality and survival forecasting has hindered the system's ability to adapt to a "super-aged" demographic profile. Recent research indicates that Puerto Rico is experiencing a "kinlessness" crisis, where the mass outmigration of working age adults has severed traditional family caregiving networks (Amilcar Matos-Moreno et al. 2022). Without accurate projections to signal the magnitude of this shift, the formal healthcare infrastructure remains ill-equipped to handle the resulting surge in age-related chronic conditions, such as Alzheimer's and cardiovascular disease. This lack of preparation was tragically underscored by significant "excess mortality" in recent years, where death rates for those over 65 reached levels far beyond historical expectations (Schmidt and Hernandez 2023). These outcomes suggest that the healthcare system is failing to keep pace with the island's unique survival patterns, as resources are often allocated based on outdated or retrospective data rather than the dynamic reality of an aging society.

Furthermore, the inability to accurately project mortality trends has complicated the island's long term recovery and debt restructuring efforts. Strategic documents, such as the certified fiscal plans issued by the Financial Oversight and Management Board, rely heavily on population forecasts to determine Puerto Rico's future debt paying capacity (Puerto Rico Fiscal Agency and Financial Advisory Authority 2024). When these projections fail to capture the true speed of demographic decline or the volatility of mortality following natural disasters, the resulting "demographic surprises" can derail years of fiscal planning. The recurring need to revise these plans in the face of unexpected population shifts demonstrates that demographic knowledge is not a luxury, but a fundamental requirement for the island's survival. Without the implementation of modern computerized tools to bridge this information gap, Puerto Rico remains in a reactive stance, unable to proactively address the economic and social consequences of its shifting survival landscape.

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