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MPIDR Working Paper WP 2023-002 I February 2023
https://doi.org/10.4054/MPIDR-WP-2023-002

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ABSTRACT

Existing research on multimorbidity (two or more co-existing chronic diseases) has mainly been cross-sectional, prevalence-based, and from high-income countries, although rates of chronic diseases and related mortality are highest in low- and middle-income countries. There is also a lack of research comparing countries at varying levels of development to determine how multimorbidity progression might differ. This study uses longitudinal data from Costa Rica, Mexico, and the United States and an incidence-based multistate Markov approach to estimate multimorbid life expectancy (MMLE): the years someone is expected to live with multimorbidity. We disaggregate MMLE into disability-free and disabling states to understand severity progression and stratify models by gender and education to study within-country heterogeneity. Individuals from Costa Rica have the lowest MMLE, followed by those from Mexico, then the United States. Individuals from the United States spend about twice as long with disability-free MMLE compared to others. Women generally have higher MMLE than men across countries. In the United States, disability-free MMLE increases and disabling MMLE decreases with education. This study found widespread MMLE inequalities in gender, education, and disability status. More attention must be paid to the drivers of these disparities, such as life course and health system differences across contexts.

INTRODUCTION

Multimorbidity – defined as the co-existence of two or more chronic diseases – is an increasingly important global public health issue (The Academy of Medical Sciences, 2018; Whitty et al., 2020). This is because the number of people with multimorbidity has been steadily increasing worldwide and this number is projected to continue rising as populations age (Kingston et al., 2018). As people accumulate diseases, they become increasingly susceptible to additional diseases, especially because certain conditions tend to cluster (Whitty et al., 2020). In many countries, particularly those of low- or middle-income or those with fragmented health systems, multimorbidity is very difficult to manage due to the complexities associated with different co-occurring diseases, such as the need for multiple medical specialists and medications (Basto-Abreu et al., 2022). Additionally, the social and healthcare structures and resources available to help diagnose and manage multimorbidity vary considerably both within and between countries.

In the extant literature on multimorbidity, there are some notable gaps and weaknesses. First, great attention has been paid to prevalence and clustering of diseases at single time points, at the expense of longitudinal approaches (Cezard et al., 2021). The emphasis on cross-sectional analysis inhibits our understanding of individual and population-level risk factors for disease development (Head et al., 2021). Second, of the longitudinal multimorbidity research that has been conducted, most has been conducted in high-income settings (Cezard et al., 2021), where the availability of detailed administrative health data makes the topic easier to investigate. By contrast, in low- and middle-income countries (LMICs), where disease constellations are likely to differ, and the epidemiological transition is more protracted, there is sparse evidence of how multimorbidity trajectories develop over time (Abebe et al., 2020). Third, there are few studies which compare multimorbidity across high-income and low- or middle-income countries; the focus is usually on one group or the other. When countries of multiple income levels are included, it is usually in the form of a systematic

review or global comparison rather than a focus on specific countries (Assari & Lankarani, 2015; Garin et al., 2016; Ho et al., 2021; Nguyen et al., 2019; Pathirana & Jackson, 2018). Since multimorbidity is a condition that has myriad combinations and requires more complex care, it is important to determine if there are differences in multimorbidity development and progression across various contexts.

One approach to understanding multimorbidity burden is to compare the time spent living with multimorbidity, or multimorbid life expectancy (MMLE) (Lam et al., 2022) and how it varies by context and social groups. As opposed to prevalence, which provides a general estimate of disease burden in a population at a certain time, MMLE accounts for the nuances of multimorbidity progression within a demographic framework. Existing research has calculated years lived with multimorbidity, usually to confirm the expansion of morbidity theory (time with ill health increases as life expectancy increases (Gruenberg, 1977)) (Kingston et al., 2018; Payne, 2022; Tetzlaff et al., 2017) or to determine when prevention programmes should be implemented across the life course (Botes et al., 2018; Chan et al., 2019). However, almost all studies have been conducted in high-income countries. Comparative estimates of MMLE in LMICs could help inform prevention and intervention programmes, identify long-term care needs, and therefore assist with the allocation of costs and resources.

Multimorbidity research typically measures numbers of chronic conditions, but seldom takes account of multimorbidity severity, which has implications for individuals and healthcare systems. To gain a more nuanced view of multimorbidity, we use disability as a proxy for severity and disease progression. Multimorbidity is associated with increased disability, but the amount of disability seems to vary depending on disease counts and combinations (Jindai, 2016; Quiñones et al., 2016; Sheridan et al., 2019). There is also a lack of knowledge about the burden of multimorbidity in terms of time without (or with) disability, usually represented by disability-adjusted life years (DALYs) or

years lost to disability (YLD) (The Academy of Medical Sciences, 2018). If an individual with multimorbidity has some degree of disability or functional limitation, then we can assume that their multimorbidity is more severe than in someone without disability. Many summary measures of population health focus on the time spent in full health (i.e., disability-free/disability-adjusted or healthy/health-adjusted life expectancy), implicitly dividing the lifespan into two health states (healthy/unhealthy). In this paper, we shift the focus to estimate how long on average a person might spend with one disease or disability-free multimorbidity before transitioning to a more progressed state. The lifespan thus consists of four health states which account for disease accumulation and severity. To do this, we use incidence-based Markov chain multistate models to estimate time spent with zero and one disease, and disability-free and disabling multimorbidity. This approach is advantageous compared to prevalence-based methods (e.g., the Sullivan Method) because it is less biased, particularly when incidence and mortality rates change over time (Barendregt et al., 1994; Imai & Soneji, 2007).

We additionally adopt the sociological concept of cumulative (dis)advantage (Dannefer, 1987; DiPrete & Eirich, 2006; Merton, 1968, 1988) and apply it to the idea of health and disease accumulation. We define cumulative (dis)advantage as in Hale et al. (2022), based on two risk factors, education and gender, and assume that lower MMLE is better. We also assume that having more education and being male will result in lower MMLE. Based on this, if the gender difference in MMLE (MMLE for women minus MMLE for men) is larger amongst low-educated than amongst high-educated, we can say that low-educated women experience cumulative *disadvantage*. If, however, the gender difference is larger amongst high-educated (the difference in MMLE between women and men is larger amongst high-educated) we can say that high-educated men experience cumulative *advantage*. Based on this definition, cumulative advantage and cumulative disadvantage are diametrically opposed concepts – either one or the other can occur, but not both (Hale et al., 2022). There is also the possibility of no evidence for either cumulative advantage or disadvantage, if

the educational differences are exactly the same for both men and women across education groups. In an analogical manner, multimorbidity can be thought of as a biosocial process of cumulative disadvantage, in which disease and disability accumulate over the life course, and the speed and intensity of accumulation differs based on different biological, social, and contextual characteristics. Education is one factor which can contribute to either cumulative advantage (high education) or cumulative disadvantage (low education) in multimorbidity. Further, cumulative (dis)advantage in disability and multimorbidity likely differ within and between countries due to differences in social, demographic, and structural factors (e.g., gender, age, race/ethnicity, education), as well as inequalities in access to health and social care and resources. Thus, we need to identify and understand these disparities to help inform and tailor prevention and management programmes accordingly.

Studies analysing inequalities in multimorbidity have shown that multimorbidity is more common amongst women and those of lower socioeconomic status (SES) in high-income countries (Xu et al., 2017). The fact that women tend to have more disease than men is well-established across several different countries regardless of income level (Abebe et al., 2020; Agur et al., 2016; Garin et al., 2016; Xu et al., 2017), and is attributable to biological differences and differences in health behaviours and thresholds for healthcare seeking (Afshar et al., 2017; Höhn et al., 2020; Mateos et al., 2022; Oksuzyan et al., 2010).

By contrast, the relationship between education and multimorbidity is less consistent. This could be due to heterogeneity in measurement of multimorbidity across studies (Ho et al., 2021), or the fact that individual chronic diseases and risk factors have different associations with SES. For example, there may be a positive association between SES and obesity, a negative association between SES and cardiovascular disease and arthritis, and mixed results for SES and diabetes (Dinsa et al., 2012; Hosseinpoor et al., 2012; Sommer et al., 2015; Williams et al., 2018). Context also plays a role in the

relationship between education and multimorbidity. In many LMICs, people with less education tend to have more multimorbidity, but the magnitude and direction of the association is not always consistent either within or across LMICs, likely due to different levels of development and access to resources (Asogwa et al., 2022). For example, across Southeast Asia, the association between education and multimorbidity ranges from positive, to negative, to none at all (Feng et al. 2021). In Brazil, people with lower education have a higher prevalence of multimorbidity, but the educational gradient varied across regions (Andrade et al., 2022). These existing studies focused on multimorbidity prevalence, so it is less clear what the gender and socioeconomic differences might be in MMLE.

We would expect that women should be more disadvantaged, with higher MMLE compared to men because women tend to have a higher prevalence of multimorbidity. With regard to education, although people with more education generally have longer life expectancy, this may be survival with more diseases, resulting in higher MMLE. On the other hand, the less educated usually have lower life expectancy, but they may also have lower MMLE due to for example, having more fatal disease combinations or being undiagnosed. Thus, we would expect there to be a flatter educational gradient for MMLE.

To fill the gap for a longitudinal, cross-national study of multimorbidity, this study uses data from Costa Rica, Mexico, and the United States to estimate MMLE using an incidence-based Markov chain approach. More specifically, MMLE will be disaggregated into disability-free and disabling states to try and elucidate the meaning of multimorbidity in the context of life expectancy. Inequalities by gender and educational attainment will also be analysed and compared within and between countries.

Contexts of Costa Rica, Mexico, and the United States

Costa Rica, Mexico, and the United States were chosen as a comparative case study due to their geographic proximity yet varying economic indicators and health and educational system structures. The United States and Mexico both have populations several times larger than Costa Rica, and all populations are rapidly ageing (Table 1). In 1950, the percent of the population above age 60 was 5% in both Costa Rica and Mexico and 12% in the United States (United Nations Population Division, Department of Economic and Social Affairs, 2022). In 2050, these percentages are expected to increase to 31% in Costa Rica, 25% in Mexico, and 30% in the United States (United Nations Population Division, Department of Economic and Social Affairs, 2022). In 1950 in the United States, life expectancy at birth was already 68.1 years, and in 2019 it increased to 79.1 years (United Nations Population Division, Department of Economic and Social Affairs, 2022). Costa Rica and Mexico have seen tremendous improvements in life expectancy at birth, increasing from 53.8 years and 44.0 years in 1950, to 79.4 years and 74.2 years in 2019, respectively (United Nations Population Division, Department of Economic and Social Affairs, 2022). Presently, while Costa Rica and Mexico are at similar levels of GDP, on average Costa Ricans live about 5 years longer compared to Mexicans (World Bank, 2022). In contrast, the United States provides a high-income country comparison which demonstrates that high GDP and health expenditure do not translate into life expectancy gains – there are likely several other contributing factors.

One potential factor is health system differences. Costa Rica has the highest life expectancy of the three countries and is the only one with a universal healthcare system (Atun et al., 2015; Vargas & Muiser, 2013). Mexico and the United States both have fragmented systems involving a mix of public and private insurances, many of which are employer-based (Atun et al., 2015; Berchick et al., 2019). Although out-of-pocket costs are higher in Costa Rica compared to the United States (Table 1), catastrophic health expenditure (i.e., the health spending of an individual exceeds a certain level of

capacity to pay) was less than 1% in Costa Rica but approximately 7% in the United States in 2013 (Briceño Chamorro & Vargas Brenes, 2017; Liu et al., 2020).

Another factor that has contributed to the rapid gains in life expectancy in Costa Rica and Mexico is the significant reduction in infant mortality (Table 1). Alongside the decrease in infant mortality rate came changes in leading causes of death, from infectious diseases and congenital disorders to non-communicable diseases like cardiovascular disease and diabetes. Most of the participants in our study were born in the 1930s and 1940s, meaning they grew up and were educated during the first stage of the health transition (Vallin & Meslé, 2004). This health transition can be thought of as improvements in health through cycles of diverging and converging patterns of mortality, of which the timing and duration of stages can vary both within and between countries because of differential exposure to social and economic change (Vallin & Meslé, 2004). The first stage of this transition encompasses Omran's epidemiological transition theory, which states that as infectious disease mortality decreases, life expectancy and the prevalence of man-made diseases increase (Omran, 1971). The second health transition stage is the cardiovascular revolution, in which improvements have been made to decrease cardiovascular mortality (Vallin & Meslé, 2004). In Table 1, we can see that the leading causes of disease in 1950 were the most divergent across the countries. The United States was at a more advanced stage of the health transition, with non-communicable diseases as the leading causes of death. Mexico was at an earlier stage of transition, with mainly infectious and congenital diseases, and Costa Rica was at an intermediate stage, with a mix of infectious and non-communicable diseases. However, over time the leading causes in each country converged to only include non-communicable diseases. The different rates of divergence/convergence in each country also likely had differential effects on people's early life experiences and survival. This could be through mechanisms of scarring or selection, in which adverse childhood events or environments result in an increased risk of mortality in later life (scarring) or in a survival advantage to older ages (selection) (Preston et al., 1998). These differences might help explain why certain people might

develop multimorbidity or have longer life expectancy than others, depending on their characteristics as well as the context in which they grew up.

Life expectancy

Recent estimates of life expectancy and healthy life expectancy show that older people in Costa Rica tend to live longer, and in better health, than those in Mexico and the United States (Kyu et al., 2018; Payne, 2018). While in the early 1980s the countries had similar life expectancy at age 60, from 1985 onwards Costa Rican life expectancy has shown a sustained increase. It diverged from Mexico and surpassed the United States, both countries whose life expectancy has increased more slowly and stagnated in recent years (United Nations Population Division, Department of Economic and Social Affairs, 2022). This can be seen in Table 1: for both men and women, life expectancy at birth is higher in Costa Rica, and the country has made more sustained life expectancy gains than the other countries, where life expectancy has stagnated or even declined. In a study comparing life expectancy and disability-free life expectancy at age 65 across Costa Rica, Mexico, Puerto Rico, and the United States, estimates are generally comparable, but Costa Rican women are expected to spend more years with disability than women in the other countries (Payne, 2018). Another study comparing life expectancy in Costa Rica and the United States found that even though people of the highest socioeconomic quartile in the United States had better life expectancy than those of the highest quartile in Costa Rica, those of the lowest socioeconomic quartile in Costa Rica had a markedly greater mortality advantage than their counterparts in the United States (Rosero-Bixby & Dow, 2016). The authors attributed this to significantly higher lung cancer and heart disease mortality rates in the United States, as well as greater socioeconomic inequalities across certain diseases and risk factors such as diabetes, hypertension, smoking, obesity, and being uninsured (Rosero-Bixby & Dow, 2016).

Multimorbidity and disability

To the best of our knowledge, there has only been one study that has specifically investigated multimorbidity in Costa Rica (Assari & Lankarani, 2015), and another study that described the prevalence of multimorbidity in their sample, but it was not the focus of the paper (Madrigal-Leer et al., 2020). Other studies have mainly focused on one chronic disease (e.g., diabetes, chronic kidney disease, cardiovascular disease) (Evans-Meza et al., 2019; Harhay et al., 2016; Jiménez-Montero & Villegas-Barakat, 2021; Santamaría-Ulloa & Montero-López, 2020; Vega-Solano et al., 2021; Wesseling et al., 2015), psychiatric comorbidities (e.g., bipolar disorder, substance abuse, depression) (Escamilla et al., 2002; Obando et al., 2004), or frailty (Picado-Ovares et al., 2019). This is a significant gap in the literature because Costa Rica has a rapidly ageing population and unusually high life expectancy relative to its GDP compared with other countries in the region. In a study of centenarians, 79% of participants had multimorbidity, 5% reported not having any disease, and 88% had at least moderate dependence in activities of daily living (ADL) (Madrigal-Leer et al., 2020). Another study found that 65% of adults aged 60 and over had some difficulty with at least one ADL (Fernández & Alfaro, 2022). Even though life expectancy in Costa Rica is higher than its neighbouring countries, possibly due to lower rates of obesity and cardiovascular disease and its universal healthcare system (Rosero-Bixby, 2008; Rosero-Bixby & Dow, 2016), multimorbidity and disability are still highly prevalent, especially at the oldest ages.

In Mexico, multimorbidity prevalence in adults aged 50 and over ranges from 21% to 50%, depending on the type of study sample (e.g., national survey, population based cohort, long-term care facility residents, or family medicine patients), multimorbidity definition and measurement, and average age of the sample (Bao et al., 2019; Christian et al., 2020; Islas-Granillo et al., 2018; Mino-León et al., 2017; Rivera-Almaraz et al., 2018). Metabolic diseases (e.g., hypertension, diabetes) are the most prevalent type and often seem to cluster with cardiac, renal, or mental health conditions (McClellan et al., 2021; Mino-León et al., 2017; Rivera-Almaraz et al., 2018). Multimorbidity is also

associated with disability, especially cardiopulmonary and mental-musculoskeletal clusters (McClellan et al., 2021; Rivera-Almaraz et al., 2018). In a study of diabetes multimorbidity (i.e., diabetes plus at least one other disease), clusters that included depression were the only ones associated with disability (McClellan et al., 2021). The magnitude of the association between diabetes multimorbidity and disability is also lower in Mexico compared to the United States (McClellan et al., 2021). This might be due to differences in disease prevalence or disability rates, which appear higher in the United States, but could also be related to differences in factors such as mortality selection and reporting of functional limitations (Gerst-Emerson et al., 2015). The time spent with disability in Mexico also seems to be expanding over time, with the younger cohort (born 1952-1962) having a 0.27-year increase in disabled life expectancy compared to the older cohort (born 1942-1951) (Payne & Wong, 2019).

In the United States, the prevalence of multimorbidity in adults aged 55 or older starts from 58.5% and increases to over 80% for those aged 85 and older (Boersma, 2020; Buttorff et al., 2017; Rocca et al., 2014; Salive, 2013). These estimates are based on either national surveys, health records, or Medicare claims data and seem to also be influenced by multimorbidity definition and insurance status (Boersma, 2020; Buttorff et al., 2017). The most common multimorbidity combination is hypertension and arthritis, which was present in 63% of women aged 65 or older (Goodman et al., 2016; Quiñones et al., 2016). Multimorbidity was also found to be associated with disability in the United States, especially when depressive symptoms were present. Groups with depressive symptoms reported 30%-80% greater disability (Quiñones et al., 2016) or 2-3.5 times greater disability (Quiñones et al., 2019) compared to other groups with non-depressive multimorbid combinations. The time spent with chronic morbidities has increased across birth cohorts, but the time with disability has remained relatively stable (Payne, 2022). The key exception is that less advantaged groups (e.g., lower educated, non-Hispanic Black individuals) see an expansion of morbidities and disabilities across cohorts (Payne, 2022).

Education

Generally, multimorbidity is associated with lower levels of education, but this relationship may be reversed in different contexts (Afshar et al., 2015; Arokiasamy et al., 2015; Garin et al., 2016; J. T. Lee et al., 2015; Pathirana & Jackson, 2018). In Costa Rica, we can get an idea about the relationship between education and multimorbidity by looking at studies that have investigated the relationship between education and other aspects of health or mortality. One study reported that education was associated with better self-reported health (Assari & Lankarani, 2015). Other studies reported no association between education and cardiovascular disease and mortality (Rehkopf et al., 2010; Rosero-Bixby et al., 2005). A study on chronic kidney disease found that people with lower education were more likely to have chronic kidney disease and hypertension (Harhay et al., 2016).

In Mexico, there is unclear evidence for the relationship between education and multimorbidity. Some studies have found higher multimorbidity prevalence in people with less education (Arokiasamy et al., 2015; Macinko et al., 2019). Other studies have found no significant association (Garin et al., 2016; Islas-Granillo et al., 2018).

In the United States, there seem to be few studies analysing the association between education and multimorbidity. In a 2018 systematic review on socioeconomic status (SES) and multimorbidity, 10 studies were included in their meta-analysis of education and multimorbidity (Pathirana & Jackson, 2018). Of those 10 studies, only one was from the United States (Tucker-Seeley et al., 2011). That study, plus two recent ones found that low education is associated with higher likelihood of multimorbidity (Chamberlain et al., 2020; Johnson-Lawrence et al., 2017; Tucker-Seeley et al., 2011).

Gender

It is well-established that globally, women have higher rates of multimorbidity than men (Abebe et al., 2020; Agur et al., 2016; Garin et al., 2016; Xu et al., 2017). Compared to men, women tend to be

the ones who seek care more often and at earlier stages, so may have higher rates of diagnosis, but they also may be more biologically susceptible to certain diseases (Afshar et al., 2017; Höhn et al., 2020). For example, men tend to be more likely to die prematurely from fatal diseases such as stroke and cancer, whereas women develop more nonfatal diseases later in life, such as anaemia and arthritis (Rieker & Bird, 2005). Consequently, women tend to live longer than men, but in poorer health and with more disability.

Due to the lack of multimorbidity studies in Costa Rica, it is unknown what the gender differences in multimorbidity may be. However, based on other studies where women have higher prevalence of chronic disease or risk factors than men (Harhay et al., 2016; Rosero-Bixby, 2008; Santamaría-Ulloa et al., 2019; Santamaría-Ulloa & Montero-López, 2020), we can hypothesise that similar patterns may be seen for multimorbidity.

In Mexico, the average prevalence of multimorbidity in women and men above age 50 was approximately 78% and 55%, respectively (Garin et al., 2016). The largest difference was seen for the 50-59 year age group, with women having a prevalence of about 75% and men having a prevalence of about 32% (Garin et al., 2016). The prevalence of multimorbidity has also increased over time, as has the difference between men and women; in 2001, the prevalence of multimorbidity was 11 percentage points (pp) higher for women than men, and this increased to 18pp in 2018 (Rojas-Huerta et al., 2022). Women also tend to develop more complex multimorbidity (3-4 diseases), whereas men with multimorbidity died earlier (Rojas-Huerta et al., 2022).

In the United States, multimorbidity prevalence is generally higher in women than men, but the difference seems to vary across studies and decreases with age. In adults younger than 65, women have seven to eight percentage points higher multimorbidity prevalence compared to men, but for those older than 65, the prevalence is 82% for men and 81% for women (Buttorff et al., 2017).

Another study shows women have about four percentage points higher prevalence than men at ages 65-84 and that decreases to a 2.8 percentage point difference from age 85 (Salive, 2013). Additionally, multimorbidity clusters differ for men and women, with men having more multimorbidity that includes cancer while women have more multimorbidity that includes arthritis (Rocca et al., 2014).

Summary

The existing evidence on multimorbidity in Costa Rica, Mexico, and the United States is mixed, both in terms of the availability of evidence and types of measures. This study brings a novel perspective to multimorbidity research by taking an incidence-based Markov chain approach to describe the time spent living with multimorbidity (MMLE). We further disaggregate MMLE into disability-free and disabling states to better understand multimorbidity severity and apply these measures in a cross-country comparison. Additionally, by stratifying the models by gender and education, we are able to gain a more nuanced understanding of potential inequalities within these countries.

METHODS

Data

Data are from waves 1-3 (2005-2009) of the Costa Rican Study on Longevity and Healthy Aging (CRELES) Pre-1945 Cohort, waves 3-5 (2012-2018) of the Mexican Health and Aging Study (MHAS), and waves 7-14 (2004-2018) of the Health and Retirement Study (HRS) (Figure 1A). These studies are part of the Gateway to Global Aging Data (g2aging.org), and use the following versions of data: Harmonized CRELES Version A, Harmonized MHAS Version C, and RAND HRS Longitudinal File 2018 (V2) (*Health and Retirement Study, (RAND HRS Longidutinal File 2018 (V2)) Public Use Dataset.*, 2022; *RAND HRS Longitudinal File 2018 (V2)*, 2022; Rosero-Bixby et al., 2016; Wong et al., 2017).

CRELES and MHAS were modelled after the HRS with similar measures and study populations, which allows for the harmonisation of data and promotes cross-country comparisons.

CRELES recruited participants aged 60 and older, with an oversampling of older ages, and followed up participants every two years (Rosero-Bixby et al., 2013). MHAS recruited participants aged 50 and older, and their spouses regardless of age, from across Mexico (Wong et al., 2017). Waves 1 and 2 of MHAS occurred in 2001 and 2003, but wave 3 did not take place until 2012. Due to this, wave 3 was chosen as the baseline for this study because our method required evenly spaced time intervals between waves (see Multistate modelling approach section). Starting from wave 3, participants were followed-up every 3 years. HRS surveyed a nationally representative sample of people from age 50, and their spouses regardless of age, in the United States every two years, beginning from 1992 (Sonnega et al., 2014). We took wave 7 as our baseline for HRS to align the time period with that of the other studies.

We included proxy respondents in our study for various reasons. A previous study that used the Costa Rican data (CRELES) excluded proxy respondents because they tended to be older and had lower life expectancy than the self-respondents, which would bias the overall life expectancy (Rueda-Salazar et al., 2021). In our case, however, because we were interested in time spent in ill-health, it was important to ensure that the oldest and more impaired/ill participants were also included. Additionally, excluding proxy respondents would have made our Costa Rican sample too small to feasibly conduct this analysis. While this might bias the overall life expectancy we estimated, it should provide a more accurate picture of MMLE, particularly at the oldest ages.

The initial sample of CRELES, MHAS, and HRS included 2,798, 21,704, and 32,968 participants, respectively (Figure 1B). Inclusion criteria consists of participants being aged 60 or over, having at least one transition (i.e., being present for more than one wave, or dying after one wave), and

having sufficient health and sociodemographic information. MHAS and HRS participants who were initially under age 60 became eligible for inclusion once they were at least 60 years old and met the other inclusion criteria. More detailed reasons and number of participants excluded can be seen in Figure 1B. The final sample sizes were n=2,626 in CRELES, n=11,208 in MHAS, and n=22,345 in HRS.

We only analysed the characteristics of excluded participants who were at least age 60 to make them most comparable to the included participants. The average age of excluded participants from MHAS and HRS were 6.8 and 9.3 years younger than that of included participants, respectively. Excluded participants from all three surveys were more highly educated than included participants. Compared to included participants, excluded CRELES participants had higher initial prevalence of one disease and multimorbidity, excluded MHAS participants had higher initial prevalence of zero and one disease, and excluded HRS participants had higher initial prevalence of zero disease, one disease, and disability-free multimorbidity.

Measures

We define multimorbidity as concurrently having two or more of the following diseases: arthritis, cancer, diabetes, heart problems (including heart attack), hypertension, stroke, and respiratory problems. These diseases were chosen as they were the shared chronic diseases across the surveys. They are also amongst the leading causes of morbidity and mortality in this region (Vos et al., 2020). A disease was indicated as present if the participant reported ever having been told by a doctor that they had that disease. All diseases were defined as being chronic and irreversible for the purposes of this analysis. Each survey defined activities of daily living (ADLs) differently, so we created a composite ADL variable that included eating, bathing, walking, and getting in and out of bed. These ADLs were used to define whether someone had disability-free multimorbidity (no difficulty with any ADL) or disabling multimorbidity (some difficulty with at least one ADL). Disability may be reversible, or at least improved, but this usually requires some form of intervention for both the individual and

their home environment (Szanton et al., 2021; Wahl et al., 2009). Therefore, for the purposes of this study, we did not account for any reversals in disability status. Mortality information was obtained through next-of-kin or surviving family interviews for CRELES and MHAS, and through relatives or the National Death Index for the HRS. Gender was categorised as 'male' or 'female'. We defined education as the highest level of completed education, which was categorised into the following levels: 'Primary school or less', 'Secondary school', and 'Post-secondary school'.

Statistical analysis

We obtained descriptive statistics stratified by gender for each country for age, education, initial disease states, deaths, person-years of follow-up, and number of transitions between states. We also calculated the prevalence of disease at one's initial state for those age 60-69 and identified the most common multimorbid disease combinations throughout the study.

Multistate modelling approach

To estimate transitions between disease states and the share of life expectancy spent with disability-free and disabling multimorbidity, we used discrete-time multistate Markov models. Our method requires the time intervals between survey waves to be evenly spaced (Schneider et al., 2021), and in this case the time between waves is two years (CRELES and HRS) or three years (MHAS). As long as the age grids used to estimate the transition probabilities matches the spacing between survey waves, the expectancy estimates across datasets can be compared even if the time intervals differ. The states we included were 'no disease, 'one disease', 'disability-free multimorbidity', 'disabling multimorbidity', and 'death'. Individuals could remain in the same state throughout the study period, transition to a subsequent state, or die. Death is an absorbing state, meaning once someone enters that state, they cannot leave.

Multinomial logit models were used to compute transition probabilities based upon the aforementioned predictors. All models were run separately for each country and were stratified by gender. Subsequent models were additionally stratified by education. This multistate approach requires the proportions of people in each state at the starting age – 60 in our models. We estimated this proportion separately for men and women aged 60-69 to obtain a larger sample size. We computed 95% confidence intervals based on asymptotic theory and the delta method[1]. The underlying variance-covariance matrix of the multinomial logit model accounts for the complex survey designs for each dataset. These 95% confidence interval calculations have recently been developed (Schneider, 2022).

Sensitivity analyses

We conducted a sensitivity analysis in which we excluded hypertension from the definition of multimorbidity. Hypertension is included in 70% of multimorbidity studies (Ho et al., 2021). However, there is much debate about whether it is a disease, or if it is a risk factor for diseases such as diabetes and cardiovascular disease (Lancet, 2019; Stanaway et al., 2018). We hypothesise that fewer participants will have multimorbidity once hypertension is excluded, but the general patterns for MMLE should remain consistent in all countries.

Statistical analyses were conducted in Stata 17 (StataCorp, 2021) and figures were created in R version 4.2.1 (R Core Team, 2022). Expectancy estimates and confidence intervals were obtained in Stata based on the package *dtms* developed by Schneider (2022).

[1] This approach does not restrict confidence limits, which allows negative confidence limits to be produced. Since negative expectancies are impossible, the limit was set equal to zero if negative values were present.

RESULTS

Descriptive statistics

Table 2 provides descriptive characteristics of the samples, by country and gender. At entry wave, participants from Costa Rica have the highest average age (76.9 years, SD 10.3), followed by those from Mexico (70.0 years, SD 8.0), and the United States (68.9 years, SD 8.9). This distribution is likely due to the different sampling eligibility criteria of the surveys and the oversampling of the oldest ages in CRELES. People from the United States are the highest educated, with 52% and 42% having secondary and post-secondary education, respectively. In contrast, most participants from Costa Rica and Mexico have only a primary school education or less (87% and 76%, respectively). Mexico and the United States have more apparent gender gaps in education compared to Costa Rica, with more males having post-secondary education than females (Mexico: 10% vs. 4%, United States: 46% vs. 39%, Costa Rica: 6% vs 5%). The United States has the greatest share of participants entering the study with both disability-free and disabling multimorbidity, 47% and 14%, respectively. In Mexico and Costa Rica, 33% and 25% of participants enter the study with disability-free multimorbidity, and 11% and 9% enter the study with disabling multimorbidity, respectively. Across all countries, there are higher percentages of women with both types of multimorbidity compared to men – the exception being men from the United States with disability-free multimorbidity. The United States has over twice the percentage points of deaths compared to the other two countries (39% vs. 20% in Costa Rica and 18% in Mexico). This is likely due to the much longer follow-up period in the HRS data (14 years) compared to CRELES (four years) and MHAS (six years). Most participants remain in the same disease state (range: 24.6%-60.1%), but the most common transition is from disabling multimorbidity to death, with percentages ranging from 5.5%-11.7%.

Disease distributions and common multimorbidity combinations

The prevalence of diseases at the first wave of entry across countries is quite distinct. The United States had the highest prevalence of arthritis, heart problems, cancer, and stroke. Mexico had the highest prevalence of hypertension and diabetes, and Costa Rica has the highest prevalence of respiratory problems (Figure 2). The five most common multimorbidity combinations are similar, with hypertension dominating in all countries (Table 3). In Costa Rica, the three most common multimorbidity combinations are: hypertension and diabetes (21%); hypertension and arthritis (12%); and hypertension and respiratory diseases (11%). In Mexico, the three most common multimorbidity combinations are: hypertension and diabetes (20%); hypertension and arthritis (20%); and hypertension, arthritis, and diabetes (9%). Similarly, in the United States, the top three multimorbidity combinations are: hypertension and arthritis (19%); hypertension, arthritis, and heart problems (8%); and hypertension, arthritis, and diabetes (6%).

Transition probabilities

When comparing the transition probabilities across countries, there are minor differences for remaining in the same state. More differences are observed for the transitions between states. Figure 3 shows a selection of transition probabilities by age for men from each country. Complete transition probability plots for men and women are in Appendix I. Costa Ricans are most likely to transition from 1 disease or disability-free multimorbidity to disabling multimorbidity. Mexicans generally have the highest probability of transitioning to death. People from the United States tend to have the highest probabilities of transitioning from 0 disease to subsequent states and from 1 disease to disability-free multimorbidity. The patterns for men and women are generally similar, but the biggest differences can be seen for the transitions from 0 disease and 1 disease. We also observe a pattern in several transitions, such as from 1 disease to disability-free and disabling multimorbidity, which indicates that the probability of transitioning peaks around ages 75-80. The

probability of transitioning to death at younger ages increases with more disease, and this is especially apparent for women.

Average life expectancy

Average remaining life expectancy for men at age 60 is 24.3 years (95% CI 22.9-25.8) in Costa Rica, 22.9 years (95% CI 21.8-24.0) in Mexico, and 20.8 years (95% CI 20.5-21.2) in the United States (Table 3). For women at age 60, the average remaining life expectancy is 25.1 years (95% CI 23.3-26.9) in Costa Rica, 25.4 years (95% CI 24.4-26.3) in Mexico, and 23.1 years (95% CI 22.8-23.4) in the United States. More detailed life and state expectancy estimates can be found in Appendix II. Our life expectancy estimates for Costa Rican men and Mexican men and women are higher than vital statistics by about 2-3 years but are more comparable to life expectancy estimates provided by other studies (Appendix III). For the United States, our life expectancy estimate for men is very similar to vital statistics, but our life expectancy estimate for women is slightly lower. These discrepancies may be attributable to differences in study periods, study samples being healthier than the general population, and/or methods of estimating life expectancies which would produce slightly different estimates, such as prevalence versus incidence-based methods (Murakami et al., 2018).

Multimorbid life expectancy

Non-MMLE and MMLE

Costa Ricans have the highest non-MMLE, followed closely by Mexicans (Table 4). In the United States, non-MMLE is about one-third to half that of the other groups. In Costa Rica and Mexico, men have higher non-MMLE than women, whereas in the United States there is no difference. Costa Rican and Mexican men have higher non-MMLE than MMLE, but these confidence intervals overlap.

Total MMLE for men is 11.5 years in Costa Rica, 11.4 years in Mexico, and 16.3 years in the United States (Table 4). This translates into the percentage of life expectancy spent with multimorbidity being 47% in Costa Rica, 50% in Mexico, and 78% in the United States. For women, total MMLE is 15.2 years in Costa Rica, 17.2 years in Mexico, and 18.5 years in the United States. This translates into the percentage of life expectancy spent with multimorbidity being 61% in Costa Rica, 68% in Mexico, and 80% in the United States. The same patterns in MMLE and percent of remaining life expectancy are generally seen for both men and women, with people from the United States having the highest estimates, followed by those from Mexico, then Costa Rica. The exception is that Costa Rican men have slightly higher MMLE than Mexican men.

Figure 4 shows the relationship between non-MMLE, MMLE, and total life expectancy by gender and education for each country. Non-MMLE increases with life expectancy while MMLE decreases. The post-secondary educated generally have the highest life expectancy – the exception being Mexican men. In all countries, post-secondary educated men have similar or lower non-MMLE and higher MMLE compared to the lower educated groups. Opposite patterns are seen for women; post-secondary educated women have similar or higher non-MMLE and similar or lower MMLE compared to lower educated groups.

Disability-free and disabling MMLE

When we disaggregate MMLE, we observe similar patterns for disability-free MMLE as we saw for total MMLE (Figure 5). Costa Ricans have the lowest disability-free MMLE (Males: 6 years, Females: 6.6 years), followed closely by Mexicans (Males: 7 years, Females: 9.3 years). Disability-free MMLE in the United States is almost twice that in Costa Rica (Males: 11.9 years, Females: 11.1 years). In contrast, disabling MMLE is lowest in the United States, (Males: 4.4 years, Females: 7.4 years) followed by Mexico (Males: 4.4 years, Females: 7.9 years), then Costa Rica (Males: 5.5 years,

Females: 8.6 years). There are less differences between countries for disabling MMLE than for disability-free MMLE.

Gender

We observe that women have higher MMLE than men across all countries and spend significantly less time with no disease than men (Figure 5). This is particularly apparent for women from Costa Rica and Mexico, as they seem to accumulate disease earlier and spend more time with disease than their male counterparts. The greatest gender difference occurs in Mexico, with women having 5.8 more years (18 percentage points (pp)) of MMLE compared to men. This difference is 3.7 years (13pp) and 2.2 years (2pp) in Costa Rica and the United States, respectively. If we look specifically at disability-free MMLE, there is little difference between the estimates for men and women in Costa Rica. In Mexico, women have 2.3 years more disability-free MMLE than men, and in the United States, men have almost one year more disability-free MMLE than women. For disabling MMLE, women consistently have about three years more disabling MMLE than men across all three countries.

Education

We expected distinct education gradients for disability-free and disabling MMLE in each country, but these were only present for the United States (Figure 6). In the United States, it is clear that with more education, disability-free MMLE increases and disabling MMLE decreases. We see slight gradients for Mexico, but confidence intervals overlap. The picture is less clear in Costa Rica, where there is a potential gradient for disability-free MMLE in men and disabling MMLE in women but like for Mexico, confidence intervals are very wide and overlap. Thus, results for Costa Rica and Mexico should be interpreted cautiously. For men especially, the difference between disability-free and disabling MMLE is largest in the post-secondary educated group compared to the secondary and

primary educated groups. This could indicate that fewer transitions to disabling multimorbidity are occurring for the highest educated group.

Cumulative (dis)advantage

We compared the MMLE between women and men in the low-educated (primary school or less) versus high-educated (post-secondary school) groups and found that our first assumption for cumulative (dis)advantage (lower MMLE in men and the high-educated) did not fully hold (Appendix IV). Rather, low-educated men seem to have the lowest MMLE, but this could be related to their lower life expectancy more generally. Additionally, our assumption that lower MMLE is better is debatable. Less multimorbidity is clearly a better outcome, but so is more life expectancy. Since lower MMLE tends to accompany lower life expectancy, and higher MMLE tends to accompany higher life expectancy, then one could also argue that higher MMLE could be the better outcome. Due to these observations regarding our assumptions, the patterns in our analysis of cumulative (dis)advantage are not very clear, particularly for Costa Rica, but they provide a starting point for interpretation on this topic. In Costa Rica, we cannot conclude whether there is cumulative advantage or disadvantage because the difference in MMLE between women and men is positive for the low-educated group, but negative for the high-educated group. However, we did find evidence for cumulative disadvantage in Mexico and the United States (Appendix IV). The most disadvantage was found in the United States, where the difference in MMLE between women and men was 3.7 years in the low-educated group and 2.1 years in the high-educated group. There was only slight evidence of cumulative disadvantage in Mexico, with the MMLE difference between women and men being 5.9 in the low-educated group and 5.6 in the high-educated group.

Sensitivity analysis

When hypertension was excluded from the multimorbidity definition, general patterns remained the same as the main analysis. The lowest non-MMLE was seen in Costa Rica and the highest MMLE,

particularly disability-free MMLE, was found in the United States, where disability-free MMLE was 2-3.5 times higher than in Costa Rica or Mexico (Appendix V). Compared to the main analysis, we found that non-MMLE increased, MMLE decreased, and life expectancy stayed about the same in all countries. The largest shift occurred in Costa Rica, where people gained about five more years with no disease compared to people in Mexico (four years) and the United States (just over one year). Non-MMLE gains and MMLE losses were similar in Costa Rica and Mexico (about 6-7 years), whereas it was around four years in the United States. This demonstrates that hypertension plays a larger role as a multimorbid condition in Costa Rica and Mexico than in the United States.

DISCUSSION

In this paper, we used three national surveys from Costa Rica, Mexico, and the United States to examine how multimorbid life expectancy (MMLE) might differ by gender and education within and between countries. We disaggregated MMLE using disability status to try and gain a more nuanced view of multimorbidity severity and progression. By taking a discrete-time multistate modelling approach, we were able to estimate the probability for people to transition across states of disease accumulation and use those probabilities to compute total life expectancy and the time spent in states of disability-free and disabling multimorbidity.

Overall, we found that regardless of gender or education, people in Costa Rica generally lived longer, healthier lives than people in Mexico and the United States, corroborating previous studies and vital statistics (Kyu et al., 2018; Payne, 2018; World Health Organization, 2020). We observed the greatest differences in disability-free MMLE across countries, with people in the United States having almost twice the disability-free MMLE compared to people in Costa Rica, who had the lowest values. Women in all countries had higher life expectancy and MMLE than men, the biggest difference seen for disabling MMLE. We identified a positive education gradient for disability-free MMLE and a

negative education gradient for disabling MMLE in the United States, but for Costa Rica and Mexico, wide and overlapping confidence intervals preclude clear conclusions from being drawn. Thus, we recommend results be interpreted with caution. Lastly, in the United States and slightly in Mexico, there was evidence for cumulative disadvantage.

Building on other summary measures of population health which focus on time in good health (e.g., health-adjusted life expectancy, disability-free life expectancy), MMLE provides a complementary measure useful for disease management. Disability-free and disabling MMLE give an idea of how long someone might live with multimorbidity and how that time is split between disability-free and disabling states. This would allow healthcare providers to have a better understanding of how long before someone might transition to disability-free or disabling multimorbidity and try to implement preventive measures accordingly.

In addition to accounting for the multimorbidity progression timeline when thinking about prevention and management programmes, the social, structural, and contextual factors relevant to each country must also be considered. Our results identified the greatest cumulative disadvantage for MMLE occurred in the United States; the difference in MMLE between women and men in the low-educated group was almost twice that of the MMLE difference in the high-educated group. We also found that generally people who had an education of primary school or less had higher disabling MMLE than people with more education. These results demonstrate that the extent of MMLE and the magnitude of inequalities differed both within and between countries. This indicates that there are context-specific factors which likely play larger roles in determining MMLE than simply gender and education. Examples of these factors could include variations in the access, quality, and utilization of healthcare; differences in health behaviours, disease screening, diagnosis, and treatment protocols across regions; and different patterns and trajectories of multimorbidity. Future research should focus on trying to better understand the role of these factors and how they shape

the profile of multimorbidity. Additionally, these aspects must be accounted for when designing prevention and management programmes in order to ensure that everyone has equitable access to care. Costa Rica's universal health coverage, social protection programmes, and emphasis on primary care and prevention provides a strong foundation for multimorbidity prevention and management programmes to be implemented because the country achieved full population coverage since 2005 (Atun et al., 2015; Pesec et al., 2017; Vargas & Muiser, 2013). In contrast, the fragmented and costly systems of Mexico and the United States can make it difficult for some to access and afford care, with wide variation in the quality and availability of services within the countries (Carrillo-Balam et al., 2020; Collins et al., 2020; Garcia-Diaz, 2022; Rovner, 2019). This results in differential disease screening, diagnosis, and treatment both within and between countries, and makes it difficult to equitably implement interventions.

Hypertension is one condition likely to be affected by differences in screening programmes. Some countries may have different screening measures, which would influence how or when people are diagnosed, as well as how they progress through the care continuum (Geldsetzer et al., 2019). For example, if guidelines in one country indicate that hypertension should be screened for regularly, then there is likely a higher chance that it will be diagnosed. On the other hand, if regular screening is not available, then hypertension might only be diagnosed in tandem with another disease. Therefore, different screening protocol for hypertension, but also for any disease generally, can lead to underestimates of the prevalence of the condition and to lower levels of control in one country versus another (Geldsetzer et al., 2019). The effect of this on estimates of multimorbidity is unknown, but our sensitivity analysis suggests that not accounting for hypertension in multimorbidity drastically shifts the distribution of time spent in each state towards less disease. It would be beneficial for future research to evaluate the association between screening/diagnosis programmes and multimorbidity to identify the extent of underestimation and whether this might be concentrated in certain conditions.

Another factor not often considered in multimorbidity research is reversals in multimorbidity or disability. By not accounting for the potential to be cured of a chronic disease or to improve a disability, multimorbidity outcomes could appear more severe than they actually are, but it is sometimes difficult to measure when and if a chronic disease is truly cured. Cancer is one example where complete remission can occur, but generally, the conditions included in multimorbidity should be currently active, require ongoing care, and/or have permanent effects (Ho et al., 2022). We did not allow for reversals in this study due to the chronic nature of multimorbid diseases and the way diseases were measured in the surveys. Participants were asked if they had ever been diagnosed with a disease, but not about whether they recovered. Disability, on the other hand, is known to be dynamic and modifiable, with potentially high rates of recovery if interventions are taken early enough, but recovery tends to be only for the short-term (Hardy & Gill, 2004). With the type of panel data we use in this study, where waves occur every two or three years, it is difficult to accurately assess if and when reversals might occur. This is especially true if the questionnaires contain a mix of responses by self and by proxy. Previous evidence suggests that self-respondents provide less consistent reports of disability compared to proxies, but proxy respondents might over-report disabilities for people aged 65 and over, thus leading to systematic biases in disability estimates (S. Lee et al., 2004; Todorov & Kirchner, 2000).

The people who survived to older ages with multimorbidity, and particularly disabling multimorbidity, have accumulated disadvantage throughout their lives in terms of disease and disability. However, other aspects of their lives, such as their educational attainment or less quantifiable factors like resilience or selection, may give certain individuals an advantage compared to others, both within and between countries. Additionally, since Costa Rica, Mexico, and the United States have moved through the health transition at different paces and reached certain stages at different points throughout someone's life course, then this may also contribute to the between country differences we observe. For example, our result that Costa Ricans have the greatest

disabling MMLE, but also generally the longest life expectancy might indicate they are somehow more resilient than their counterparts, that the survival selection was stronger, or there are other stronger determinants at play. For example, the Costa Rican healthcare and social security system might make disease management and resources to help with disability more accessible, or older Costa Ricans might have more of a social support system to help with disability in older ages.

This study has several limitations. First, we used self-report longitudinal survey data which is prone to recall bias and loss to follow-up. Survival bias may also play a role because in order to be included in our study, participants had to have survived to at least age 60. Second, we were limited to the seven chronic conditions that were assessed across all the surveys. Therefore, our estimate of multimorbidity does not provide a robust representation of all possible disease combinations, but we at least have good representation of some of the most prevalent and burdensome. We are also likely overestimating the number of people without disease and underestimating the number of people with one disease and multimorbidity. Further, since 'respiratory problems' and 'heart problems' were each counted as only one disease due to the structure of the questionnaires, that could also contribute to an underestimation of the number of people with multimorbidity since multiple diseases could fall within those categories. Third, there was a non-negligible number of participants who were lost to follow-up, which could have introduced bias. Lastly, the small sample size and number of transitions, particularly in the CRELES and MHAS data, resulted in wide confidence intervals which precluded us from observing any clear patterns or finding statistically significant differences between several estimates. The small samples may also factor into our life expectancy estimates being larger than those reported in vital statistics, but the lower bounds of our confidence intervals were fairly close to many vital statistics and estimates from other studies (Appendix III).

In this study, we identified gender and educational inequalities for disability-free and disabling MMLE both within and between the countries of Costa Rica, Mexico, and the United States. This approach allowed us to consider how macro-level contextual determinants may be associated with micro-level health outcomes over time, and this should be further pursued in future research. The concept of MMLE, and the incorporation of disability status, can also be easily extended beyond what was done in this paper to include additional indicators of progression, such as using instrumental activities of daily living or cognitive function. MMLE is a valuable measure of population health and can be used to help healthcare professionals and policymakers identify critical periods for multimorbidity prevention and severity management.

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Tables

Table 1. Economic, population, and health indicators for Costa Rica, Mexico, and the United States

	Costa Rica			Mexico			United States		
	1950	2000	2019	1950	2000	2019	1950	2000	2019
GDP/capita, (current USD)	381 *(1960)*	3,789	12,762	345.2 *(1960)*	7,158	9,950	3,007 *(1960)*	36,330	65,095
Health expenditure (% of GDP)	-	6.6	7.3	-	4.5	5.4	-	12.5	16.7
Out-of-pocket expenditure (% of health expenditure)	-	31.6	22.3	-	52.2	42.1	-	15.1	11.3
LE at birth, men	52.2	75.3	77.0	42.4	70.7	70.9	65.4	74.1	76.6
LE at birth, women	55.5	80.0	82.0	45.6	76.5	77.6	71.0	79.4	81.7
Population size (millions)	1	4	5	28	98	125	148	282	334
Median age	17.3	24.5	32.0	16.9	21.8	28.4	29.3	34.2	37.3
% over age 60	4.8	8.5	14.4	4.8	7.3	11.5	12.2	16.2	22.1
Infant mortality rate	114.2	11.2	7.0	159.6	23.4	12.0	31.7	7.2	5.5
Leading causes of death	Infections & malnutrition, CVD & diabetes, cancer	CVD, cancer, digestive diseases	CVD, cancer, diabetes & CKD	Digestive diseases, pneumonia & influenza, congenital deformations	CVD, diabetes & CKD, cancer	CVD, diabetes & CKD, cancer	CVD, cancer, vascular lesions	CVD, cancer, stroke	CVD, cancer, accidents

CKD: Chronic kidney disease, CVD: Cardiovascular disease

Source: (Bastian et al., 2020; Institute for Health Metrics and Evaluation, 2019; Rabell & Terán, 1986; Rosero-Bixby, 1994; United Nations Population Division, Department of Economic and Social Affairs, 2022; World Bank, 2022)

Table 2. Descriptive statistics for Costa Rica, Mexico, and the United States

	Costa Rica		Mexico		United States	
	Male (N=1,200)	**Female (N=1,426)**	**Male (N=4,994)**	**Female (N=6,214)**	**Male (N=9,599)**	**Female (N=12,746)**
Mean age at entry (SD)	76.9 (10.3)	76.9 (10.2)	70.2 (7.9)	69.9 (8.1)	68.6 (8.3)	69.2 (9.2)
Educational attainment						
Primary school or less	1,040 (86.7%)	1,248 (87.5%)	3,691 (73.9%)	4,868 (78.3%)	680 (7.1%)	776 (6.1%)
Secondary school	93 (7.7%)	107 (7.5%)	784 (15.7%)	1,075 (17.3%)	4,540 (47.3%)	6,969 (54.7%)
Post-secondary school	67 (5.6%)	71 (5.0%)	519 (10.4%)	271 (4.4%)	4,379 (45.6%)	5,001 (39.2%)
Initial disease state						
0 disease	438 (36.5%)	332 (23.3%)	1,607 (32.2%)	1,048 (16.9%)	1,503 (15.7%)	1,625 (12.7%)
1 disease	436 (36.3%)	525 (36.8%)	1,662 (33.3%)	1,973 (31.8%)	2,457 (25.6%)	3,259 (25.6%)
Disability-free Multimorbidity	237 (19.8%)	413 (29.0%)	1,337 (26.8%)	2,333 (37.5%)	4,614 (48.1%)	5,871 (46.1%)
Disabling Multimorbidity	89 (7.4%)	156 (10.9%)	388 (7.8%)	860 (13.8%)	1,025 (10.7%)	1,991 (15.6%)
Deaths	253 (21.1%)	264 (18.5%)	999 (20.0%)	1,015 (16.3%)	4,002 (41.7%)	4,693 (36.8%)
Person-years of follow-up	6,212	7,470	24,892	31,222	96,420	132,964
Transitions	3,106	3,735	12,446	15,611	48,210	66,482
0 disease to 0 disease	894 (47.1%)	639 (33.6%)	3,130 (49.4%)	1,990 (31.4%)	3,843 (36.8%)	4,317 (41.4%)
0 disease to 1 disease	101 (5.3%)	94 (4.9%)	421 (6.6%)	320 (5.0%)	752 (7.2%)	858 (8.2%)
0 disease to disability-free MM	17 (0.9%)	7 (0.4%)	68 (1.1%)	60 (0.9%)	176 (1.7%)	151 (1.4%)
0 disease to disabling MM	4 (0.2%)	6 (0.3%)	21 (0.3%)	17 (0.3%)	38 (0.4%)	33 (0.3%)
0 disease to death	78 (4.1%)	59 (3.1%)	241 (3.4%)	97 (1.5%)	155 (1.5%)	109 (1.0%)
1 disease to 1 disease	903 (35.9%)	1,140 (45.3%)	3,266 (36.3%)	3,857 (42.9%)	7,443 (32.1%)	10,447 (45.1%)
1 disease to disability-free MM	101 (4.0%)	90 (3.6%)	458 (5.1%)	474 (5.3%)	1,636 (7.1%)	2,000 (8.6%)
1 disease to disabling MM	45 (1.8%)	66 (2.6%)	142 (1.6%)	213 (2.4%)	268 (1.2%)	457 (2.0%)
1 disease to death	87 (3.5%)	86 (3.4%)	288 (3.2%)	288 (3.2%)	436 (1.9%)	466 (2.0%)
Disability-free MM to disability-free MM	540 (30.5%)	911 (51.4%)	2,856 (30.3%)	5,028 (53.4%)	22,900 (38.8%)	28,694 (48.7%)
Disability-free MM to disabling MM	73 (4.1%)	154 (8.7%)	270 (2.9%)	647 (6.9%)	1,495 (2.5%)	2,555 (4.3%)
Disability-free MM to death	40 (2.3%)	53 (3.0%)	315 (3.3%)	308 (3.3%)	1,796 (3.0%)	1,525 (2.6%)
Disabling MM to disabling MM	175 (26.8%)	364 (55.7%)	815 (24.6%)	1,990 (60.1%)	5,657 (25.5%)	12,277 (55.4%)
Disabling MM to death	48 (7.4%)	66 (10.1%)	182 (5.5%)	322 (9.7%)	1,615 (7.3%)	2,593 (11.7%)

MM: Multimorbidity

Table 3. Top five most common multimorbidity clusters in Costa Rica, Mexico, and the United States

Country	**Multimorbidity cluster**	**Percentage**
Costa Rica	Hypertension + Diabetes	20.6
	Hypertension + Arthritis	11.9
	Hypertension + Respiratory problems	10.8
	Hypertension + Diabetes + Respiratory problems	5.8
	Hypertension + Arthritis + Diabetes	4.7
Mexico	Hypertension + Diabetes	20.4
	Hypertension + Arthritis	20.2
	Hypertension + Arthritis + Diabetes	9.4
	Hypertension + Respiratory problems	4.7
	Hypertension + Heart problems	4.1
United States	Hypertension + Arthritis	18.9
	Hypertension + Arthritis + Heart problems	7.5
	Hypertension + Arthritis + Diabetes	5.9
	Hypertension + Heart problems	4.6
	Hypertension + Diabetes	4.4

Table 4. Average state and life expectancies at age 60, by country and gender.

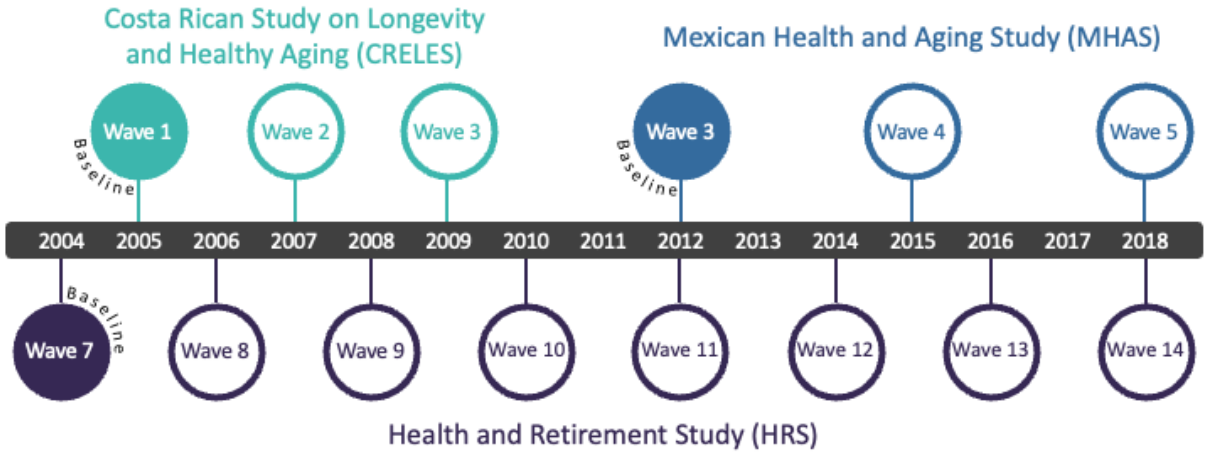
Country	Gender	Target state	Average expectancy	Lower 95% CI	Upper 95% CI	% of total life expectancy [a]
Costa Rica	Male	0 disease	6.2	5.5	7.0	25.6
		1 disease	6.6	5.6	7.5	26.9
		Disability-free multimorbidity	6.0	5.1	6.9	24.8
		Disabling multimorbidity	5.5	4.2	6.9	22.7
		Non-MMLE	12.8	11.1	14.5	52.5
		MMLE	11.5	9.3	13.8	47.5
		Total life expectancy	24.3	22.9	25.8	100.0
	Female	0 disease	2.5	1.9	3.0	9.9
		1 disease	7.5	6.6	8.5	29.9
		Disability-free multimorbidity	6.6	5.7	7.4	26.1
		Disabling multimorbidity	8.6	7.2	10.0	34.2
		Non-MMLE	10.0	8.5	11.5	39.8
		MMLE	15.2	12.9	17.4	60.2
		Total life expectancy	25.1	23.3	26.9	100.0
Mexico	Male	0 disease	4.9	4.4	5.5	21.4
		1 disease	6.6	5.8	7.3	28.7
		Disability-free multimorbidity	7.0	6.2	7.7	30.5
		Disabling multimorbidity	4.4	3.6	5.3	19.4
		Non-MMLE	11.5	10.2	12.8	50.1
		MMLE	11.4	9.8	13	49.9
		Total life expectancy	22.9	21.8	24	100.0
	Female	0 disease	2.5	2.3	2.8	9.9
		1 disease	5.6	5.2	6.1	22.1
		Disability-free multimorbidity	9.3	8.6	9.9	36.6
		Disabling multimorbidity	7.9	7.0	8.9	31.3
		Non-MMLE	8.1	7.5	8.9	32.1
		MMLE	17.2	15.6	18.8	67.9
		Total life expectancy	25.4	24.4	26.3	100.0
United States	Male	0 disease	1.4	1.3	1.5	6.8
		1 disease	3.2	3.0	3.3	15.3
		Disability-free multimorbidity	11.9	11.6	12.2	57.0
		Disabling multimorbidity	4.4	4.1	4.6	20.9
		Non-MMLE	4.6	4.3	4.8	22.1
		MMLE	16.3	15.7	16.8	77.9
		Total life expectancy	20.8	20.5	21.2	100.0
	Female	0 disease	1.3	1.2	1.4	5.6
		1 disease	3.3	3.1	3.4	14.1
		Disability-free multimorbidity	11.1	10.9	11.4	48.1
		Disabling multimorbidity	7.4	7.2	7.7	32.2
		Non-MMLE	4.6	4.3	4.8	19.7
		MMLE	18.5	18.1	19.1	80.3
		Total life expectancy	23.1	22.8	23.4	100.0

MMLE: Multimorbid life expectancy

[a] The percent of total life expectancy calculated here is based on unrounded average expectancies and thus may differ slightly from percentages based on the rounded average expectancies presented in the table.

Figures

A



B

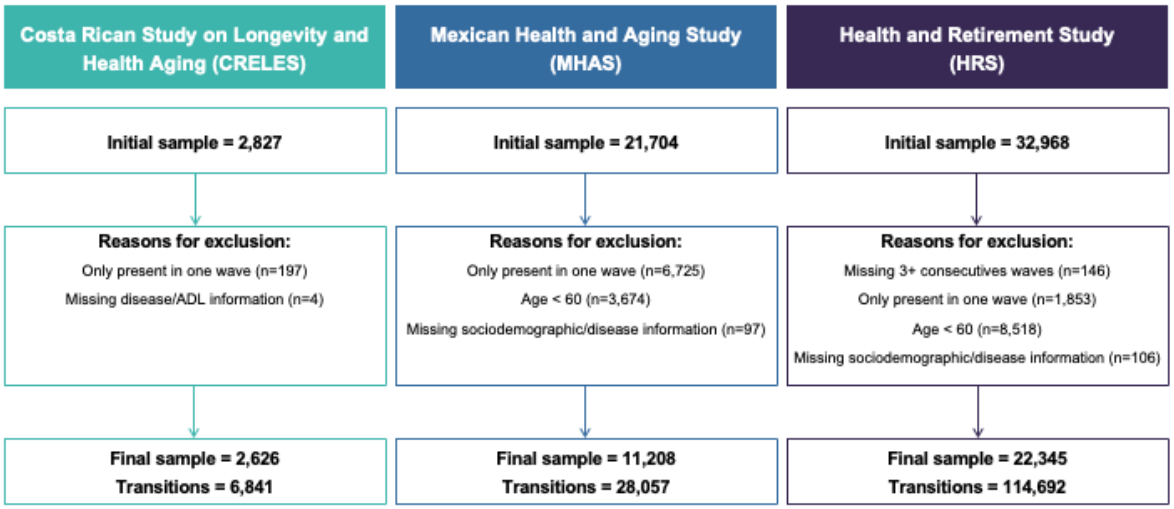


Figure 1. A) Included study waves and years and B) sample size and reasons for exclusion from CRELES, MHAS, and HRS

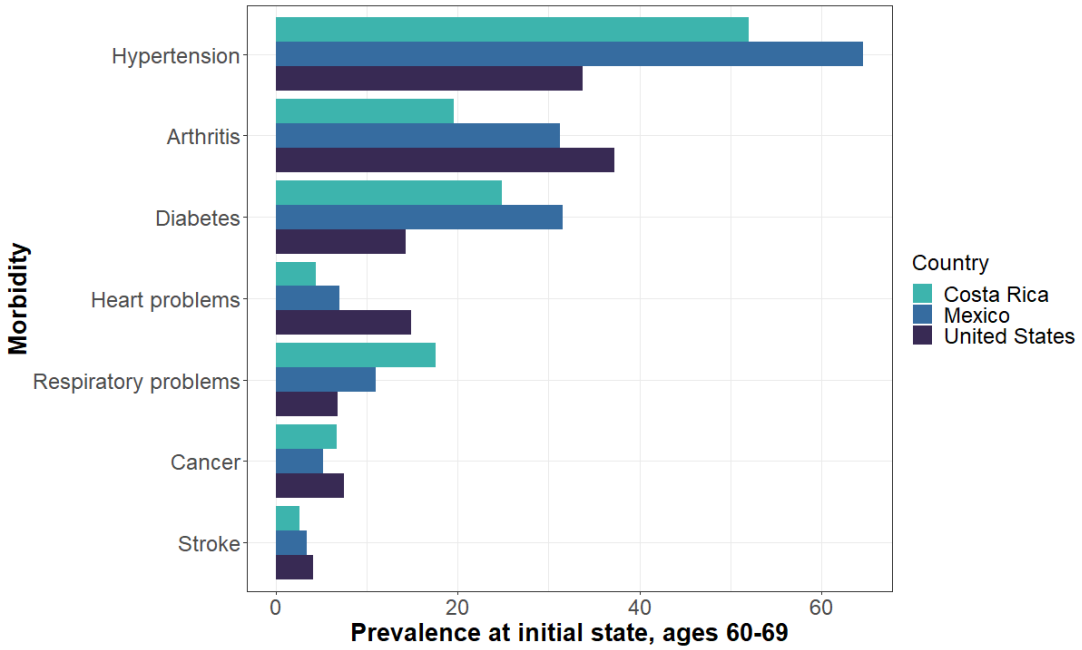


Figure 2. Prevalence at initial state for ages 60-69 in Costa Rica, Mexico, and the United States.

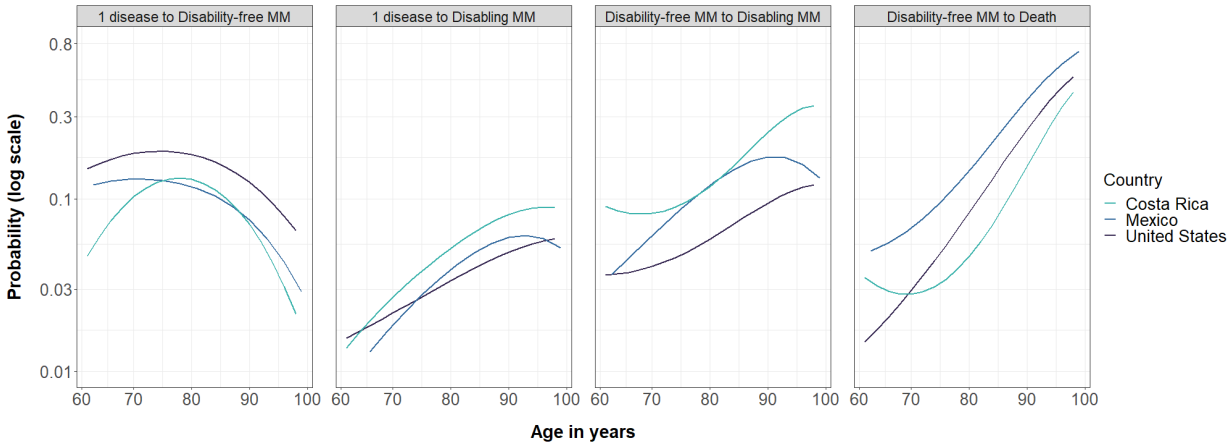


Figure 3. Probabilities of transitioning between selected states for men in Costa Rica, Mexico, and the United States.

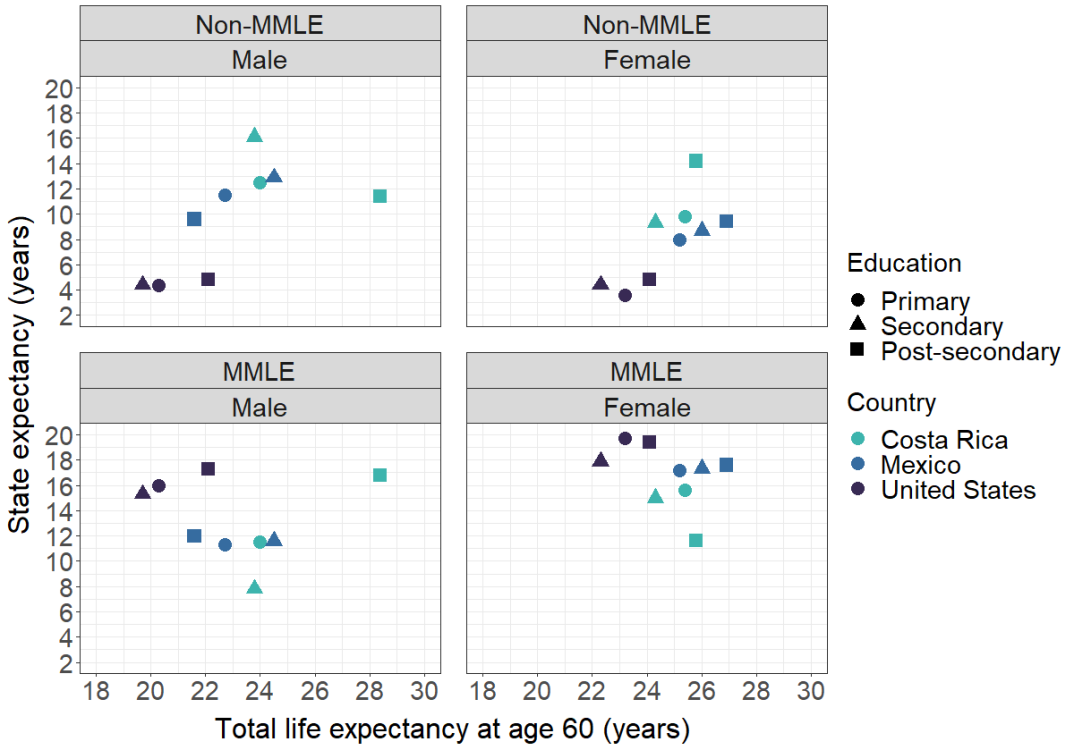


Figure 4. Relationship of non-multimorbid life expectancy (Non-MMLE) and multimorbid life expectancy (MMLE) with total life expectancy, by gender, country, and education level

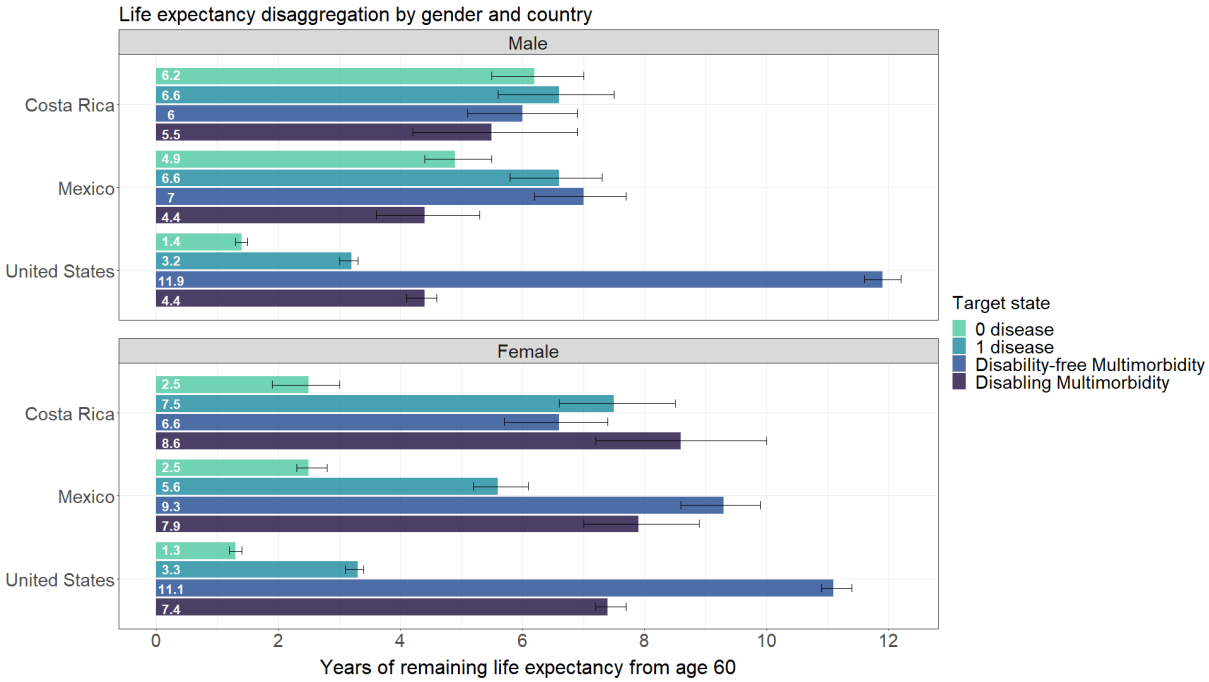
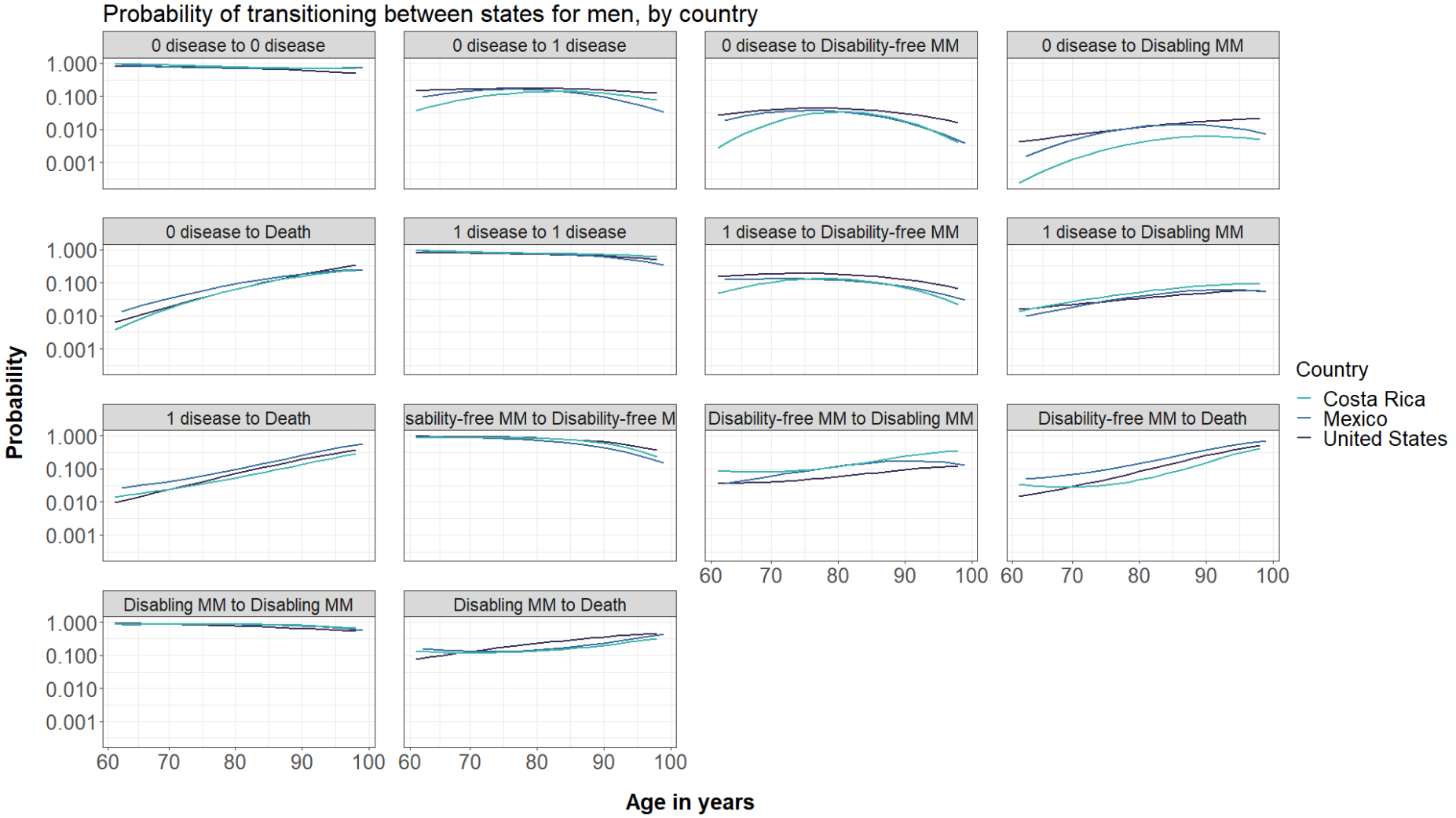


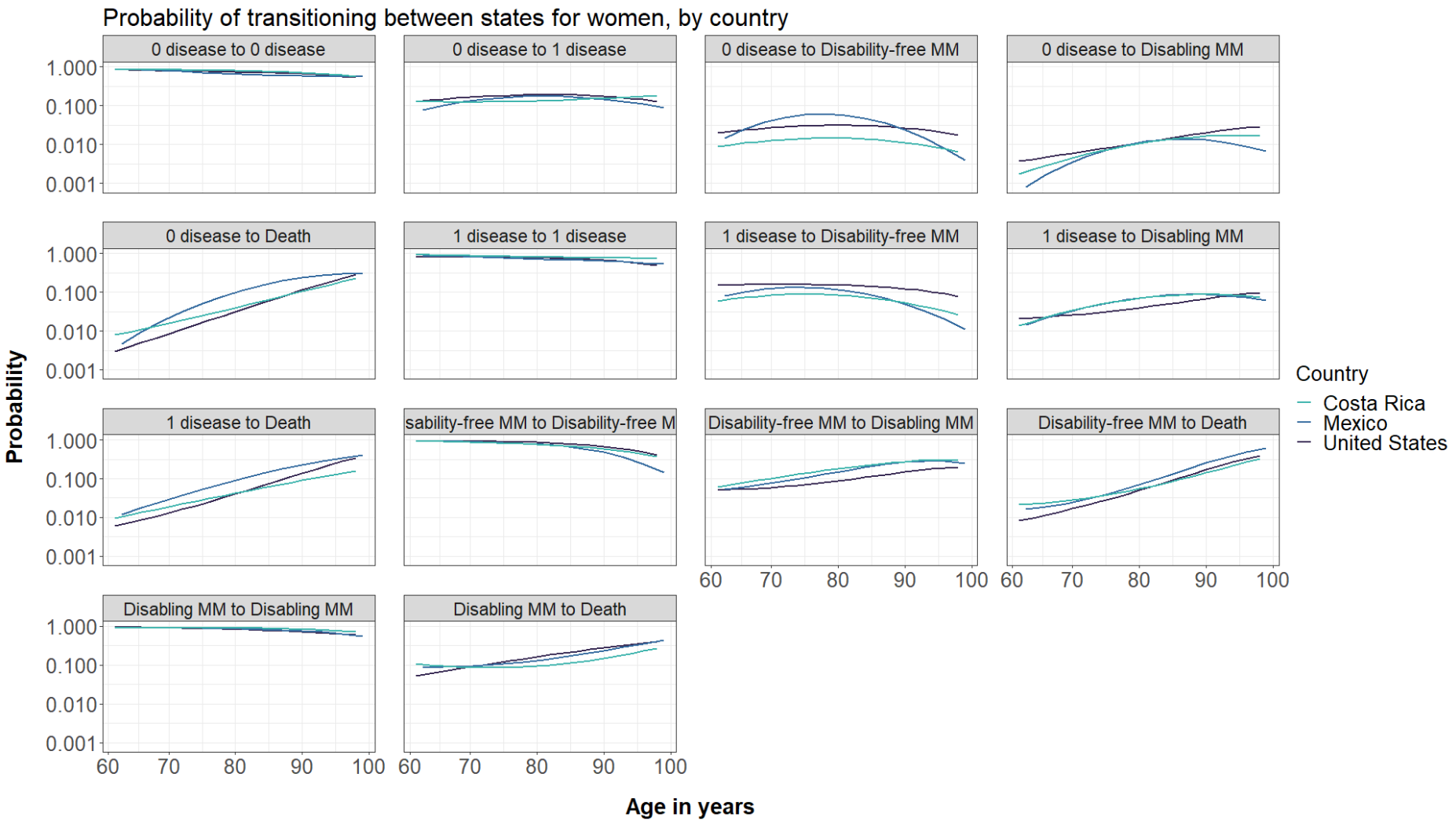
Figure 5. Years from age 60 spent in each target disease state. Stratified by country and gender.

Figure 6. Average life expectancy at age 60 spent in each target disease state. Stratified by country, gender, and education.

SUPPLEMENTARY MATERIAL

Appendix I: Transition probability plots




Probability of transitioning between states for women, by country
0 disease to 0 disease
0 disease to 1 disease
0 disease to Disability-free MM
0 disease to Disabling MM
0 disease to Death
1 disease to 1 disease
1 disease to Disability-free MM
1 disease to Disabling MM
1 disease to Death
sability-free MM to Disability-free M
Disability-free MM to Disabling MM
Disability-free MM to Death
Disabling MM to Disabling MM
Disabling MM to Death
1.000
0.100
0.010
0.001
60
70
80
90
100
Probability
Age in years
Country
Costa Rica
Mexico
United States

Appendix II. Expected number of years spent in each target disease state, and total remaining life expectancy, from a given initial disease state at age 60.

CRELES

Males

	Initial state														
Target State	0 disease	95% CI		1 disease	95% CI		Disability-free Multimorbidity	95% CI		Disabling Multimorbidity	95% CI		Average	95% CI	
0 disease	14.2	12.5	15.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.2	5.5	7.0
1 disease	5.5	4.5	6.5	12.3	10.3	14.3	0.0	0.0	0.0	0.0	0.0	0.0	6.6	5.6	7.5
Disability-free Multimorbidity	3.4	2.7	4.0	6.2	5.1	7.2	13.0	10.8	15.2	0.0	0.0	0.0	6.0	5.1	6.9
Disabling Multimorbidity	3.5	2.4	4.5	5.9	4.5	7.3	8.2	5.9	10.5	13.5	8.2	18.7	5.5	4.2	6.9
Total	26.5	25.3	27.8	24.3	22.4	26.3	21.2	18.9	23.6	13.5	8.2	18.7	24.3	22.9	25.8

Females

	Initial state														
Target State	0 disease	95% CI		1 disease	95% CI		Disability-free Multimorbidity	95% CI		Disabling Multimorbidity	95% CI		Average	95% CI	
0 disease	10.9	8.5	13.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	1.9	3.0
1 disease	8.2	6.8	9.5	13.2	11.4	15.0	0.0	0.0	0.0	0.0	0.0	0.0	7.5	6.6	8.5
Disability-free Multimorbidity	2.8	2.1	3.6	4.8	3.9	5.7	12.7	11.4	14.0	0.0	0.0	0.0	6.6	5.7	7.4
Disabling Multimorbidity	5.6	4.7	6.6	8.0	6.7	9.3	10.6	8.7	12.6	16.6	12.3	21.0	8.6	7.2	10.0
Total	27.5	26.0	29.0	26.0	24.1	27.8	23.3	20.9	25.7	16.6	12.3	21.0	25.1	23.3	26.9

Males - Primary education

	Initial state														
Target State	0 disease	95% CI		1 disease	95% CI		Disability-free Multimorbidity	95% CI		Disabling Multimorbidity	95% CI		Average	95% CI	
0 disease	13.3	11.5	15.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.8	5.0	6.6
1 disease	5.9	4.8	6.9	12.4	10.3	14.5	0.0	0.0	0.0	0.0	0.0	0.0	6.7	5.7	7.8
Disability-free Multimorbidity	3.3	2.6	3.9	5.6	4.8	6.5	12.1	9.8	14.4	0.0	0.0	0.0	5.7	4.8	6.5
Disabling Multimorbidity	3.7	2.7	4.8	6.1	4.7	7.6	8.7	6.2	11.2	13.8	8.5	19.0	5.8	4.4	7.3
Total	26.1	24.8	27.5	24.2	22.2	26.1	20.8	18.2	23.4	13.8	8.5	19.0	24.0	22.4	25.7

Males - Secondary education

	Initial state														
Target State	0 disease	95% CI		1 disease	95% CI		Disability-free Multimorbidity	95% CI		Disabling Multimorbidity	95% CI		Average	95% CI	
0 disease	20.5	12.7	28.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.0	5.6	12.4
1 disease	4.9	2.0	7.8	14.6	10.2	19.0	0.0	0.0	0.0	0.0	0.0	0.0	7.1	4.6	9.5
Disability-free Multimorbidity	2.1	0.3	3.8	6.0	2.7	9.4	14.7	8.8	20.6	0.0	0.0	0.0	5.8	3.0	8.5
Disabling Multimorbidity	0.9	0.0	2.3	2.1	0.0	5.3	3.4	0.0	8.2	6.7	0.0	15.1	2.0	0.0	4.8
Total	28.4	22.6	34.1	22.8	17.0	28.5	18.1	12.6	23.5	6.7	0.0	15.1	23.8	18.8	28.8

Males - Post-secondary education

	Initial state														
Target State	0 disease	95% CI		1 disease	95% CI		Disability-free Multimorbidity	95% CI		Disabling Multimorbidity	95% CI		Average	95% CI	
0 disease	16.3	8.1	24.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.1	3.6	10.7
1 disease	3.3	1.2	5.5	8.6	5.3	11.8	0.0	0.0	0.0	0.0	0.0	0.0	4.3	2.4	6.2
Disability-free Multimorbidity	5.8	2.9	8.8	11.1	4.9	17.3	17.4	10.2	24.7	0.0	0.0	0.0	9.6	5.3	14.0
Disabling Multimorbidity	4.5	0.0	9.2	8.2	1.8	14.7	9.8	2.4	17.2	18.2	7.4	29.0	7.2	1.4	13.1
Total	30.0	24.4	35.5	27.9	22.1	33.7	27.2	20.6	33.8	18.2	7.4	29.0	28.4	22.7	34.0

Females - Primary education

	Initial state														
Target State	0 disease	95% CI		1 disease	95% CI		Disability-free Multimorbidity	95% CI		Disabling Multimorbidity	95% CI		Average	95% CI	
0 disease	11.0	8.5	13.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	2.0	3.1
1 disease	7.9	6.6	9.1	12.9	11.2	14.6	0.0	0.0	0.0	0.0	0.0	0.0	7.3	6.4	8.2
Disability-free Multimorbidity	2.6	1.9	3.3	4.4	3.6	5.3	11.8	10.4	13.2	0.0	0.0	0.0	6.1	5.2	6.9
Disabling Multimorbidity	6.1	4.8	7.4	8.8	7.2	10.4	11.8	9.6	13.9	18.0	13.6	22.4	9.5	7.8	11.1
Total	27.6	25.9	29.3	26.2	24.3	28.0	23.6	20.9	26.2	18.0	13.6	22.4	25.4	23.4	27.3

Females - Secondary education

	Initial state														
Target State	0 disease	95% CI		1 disease	95% CI		Disability-free Multimorbidity	95% CI		Disabling Multimorbidity	95% CI		Average	95% CI	
0 disease	11.3	4.0	18.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.6	0.9	4.2
1 disease	7.1	3.6	10.7	11.7	6.8	16.6	0.0	0.0	0.0	0.0	0.0	0.0	6.7	3.9	9.4
Disability-free Multimorbidity	4.9	0.9	9.0	8.4	3.3	13.6	17.4	12.3	22.4	0.0	0.0	0.0	10.0	5.5	14.5
Disabling Multimorbidity	3.3	1.0	5.5	4.7	1.3	8.2	5.9	1.5	10.3	11.7	3.6	19.8	5.0	1.5	8.6
Total	26.6	21.7	31.5	24.9	20.2	29.6	23.3	17.3	29.2	11.7	3.6	19.8	24.3	19.4	29.2

Females - Post-secondary education

	Initial state														
Target State	0 disease	95% CI		1 disease	95% CI		Disability-free Multimorbidity	95% CI		Disabling Multimorbidity	95% CI		Average	95% CI	
0 disease	8.7	2.5	14.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.6	3.4
1 disease	14.9	8.1	21.7	20.4	12.2	28.6	0.0	0.0	0.0	0.0	0.0	0.0	12.2	7.2	17.1
Disability-free Multimorbidity	3.4	0.2	6.6	5.0	1.1	8.9	16.9	11.5	22.3	0.0	0.0	0.0	8.0	4.3	11.8
Disabling Multimorbidity	2.2	0.0	4.8	2.8	0.0	6.1	5.0	0.0	10.3	10.0	0.2	19.7	3.6	0.0	7.5
Total	29.2	22.8	35.6	28.2	21.6	34.8	21.9	14.3	29.5	10.0	0.2	19.7	25.8	19.5	32.1

MHAS

Males

	Initial state														
Target State	0 disease	95% CI		1 disease	95% CI		Disability-free Multimorbidity	95% CI		Disabling Multimorbidity	95% CI		Average	95% CI	
0 disease	12.4	11.0	13.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.9	4.4	5.5
1 disease	6.5	5.4	7.5	12.7	11.2	14.2	0.0	0.0	0.0	0.0	0.0	0.0	6.6	5.8	7.3
Disability-free Multimorbidity	3.3	2.6	4.0	6.4	5.3	7.4	15.2	13.9	16.6	0.0	0.0	0.0	7.0	6.2	7.7
Disabling Multimorbidity	2.6	1.9	3.2	4.0	3.2	4.8	5.7	4.4	6.9	16.2	13.2	19.2	4.4	3.6	5.3
Total	24.8	23.7	25.8	23.1	21.8	24.3	20.9	19.1	22.7	16.2	13.2	19.2	22.9	21.8	24.0

Females

	Initial state														
Target State	0 disease	95% CI		1 disease	95% CI		Disability-free Multimorbidity	95% CI		Disabling Multimorbidity	95% CI		Average	95% CI	
0 disease	12.8	11.4	14.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	2.3	2.8
1 disease	6.2	5.2	7.3	13.6	12.5	14.6	0.0	0.0	0.0	0.0	0.0	0.0	5.6	5.2	6.1
Disability-free Multimorbidity	3.8	3.0	4.6	6.3	5.4	7.1	17.0	15.9	18.1	0.0	0.0	0.0	9.3	8.6	9.9
Disabling Multimorbidity	3.8	3.1	4.6	6.1	5.2	7.0	8.7	7.5	9.8	19.6	17.4	21.8	7.9	7.0	8.9
Total	26.6	25.4	27.9	25.9	24.9	26.9	25.7	24.5	26.8	19.6	17.4	21.8	25.4	24.4	26.3

Males - Primary education

	Initial state														
Target State	0 disease	95% CI		1 disease	95% CI		Disability-free Multimorbidity	95% CI		Disabling Multimorbidity	95% CI		Average	95% CI	
0 disease	13.1	11.3	14.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.1	4.4	5.7
1 disease	6.3	5.0	7.5	12.4	10.8	14.0	0.0	0.0	0.0	0.0	0.0	0.0	6.4	5.6	7.3
Disability-free Multimorbidity	3.0	2.4	3.7	6.1	5.0	7.2	14.5	13.2	15.9	0.0	0.0	0.0	6.7	5.9	7.4
Disabling Multimorbidity	2.6	1.9	3.3	4.2	3.2	5.1	5.9	4.5	7.2	16.3	13.1	19.5	4.6	3.7	5.5
Total	24.9	23.8	26.1	22.7	21.3	24.0	20.4	18.7	22.1	16.3	13.1	19.5	22.7	21.5	23.8

Males - Secondary education

	Initial state														
Target State	0 disease	95% CI		1 disease	95% CI		Disability-free Multimorbidity	95% CI		Disabling Multimorbidity	95% CI		Average	95% CI	
0 disease	12.4	9.1	15.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.9	3.6	6.2
1 disease	8.3	5.7	10.9	15.0	11.6	18.4	0.0	0.0	0.0	0.0	0.0	0.0	8.0	6.0	10.0
Disability-free Multimorbidity	3.5	1.2	5.9	6.5	3.1	9.8	16.6	12.0	21.2	0.0	0.0	0.0	7.4	4.4	10.4
Disabling Multimorbidity	2.4	0.6	4.1	3.6	1.2	6.0	5.5	2.0	8.9	16.6	9.4	23.7	4.2	1.6	6.7
Total	26.6	22.9	30.3	25.0	20.8	29.2	22.0	15.8	28.3	16.6	9.4	23.7	24.5	20.1	28.9

Males - Post-secondary education

	Initial state														
Target State	0 disease	95% CI		1 disease	95% CI		Disability-free Multimorbidity	95% CI		Disabling Multimorbidity	95% CI		Average	95% CI	
0 disease	9.5	5.8	13.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.7	2.3	5.2
1 disease	6.1	2.5	9.7	10.9	5.8	16.0	0.0	0.0	0.0	0.0	0.0	0.0	5.9	2.9	8.8
Disability-free Multimorbidity	5.7	1.6	9.9	9.3	3.5	15.1	18.4	13.0	23.7	0.0	0.0	0.0	9.6	5.0	14.2
Disabling Multimorbidity	1.5	0.2	2.7	2.0	0.4	3.7	2.6	0.5	4.7	11.0	4.9	17.1	2.4	0.6	4.2
Total	22.8	18.1	27.5	22.2	17.7	26.7	21.0	15.1	26.9	11.0	4.9	17.1	21.6	16.9	26.2

Females - Primary education

	Initial state														
Target State	0 disease	95% CI		1 disease	95% CI		Disability-free Multimorbidity	95% CI		Disabling Multimorbidity	95% CI		Average	95% CI	
0 disease	12.4	10.9	13.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.4	2.2	2.7
1 disease	6.2	5.2	7.3	13.4	12.3	14.6	0.0	0.0	0.0	0.0	0.0	0.0	5.6	5.1	6.1
Disability-free Multimorbidity	3.8	3.0	4.7	6.2	5.3	7.1	16.8	15.8	17.8	0.0	0.0	0.0	9.2	8.5	9.9
Disabling Multimorbidity	3.9	3.1	4.7	6.2	5.2	7.1	8.8	7.6	9.9	19.6	17.4	21.9	8.0	7.1	9.0
Total	26.4	25.1	27.7	25.8	24.8	26.8	25.6	24.4	26.7	19.6	17.4	21.9	25.2	24.2	26.2

Females - Secondary education

	Initial state														
Target State	0 disease	95% CI		1 disease	95% CI		Disability-free Multimorbidity	95% CI		Disabling Multimorbidity	95% CI		Average	95% CI	
0 disease	15.5	11.4	19.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.1	2.2	3.9
1 disease	5.7	3.4	8.0	13.8	10.9	16.7	0.0	0.0	0.0	0.0	0.0	0.0	5.6	4.3	6.9
Disability-free Multimorbidity	3.6	1.8	5.3	6.9	4.1	9.6	18.0	14.4	21.6	0.0	0.0	0.0	9.8	7.4	12.3
Disabling Multimorbidity	3.2	1.4	5.0	5.8	2.9	8.7	8.2	4.1	12.2	19.5	14.1	24.9	7.5	4.3	10.7
Total	28.0	25.3	30.7	26.5	23.7	29.2	26.2	23.2	29.1	19.5	14.1	24.9	26.0	23.2	28.8

Females - Post-secondary education

	Initial state														
Target State	0 disease	95% CI		1 disease	95% CI		Disability-free Multimorbidity	95% CI		Disabling Multimorbidity	95% CI		Average	95% CI	
0 disease	10.2	5.2	15.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	1.0	3.0
1 disease	9.8	3.8	15.8	16.8	10.5	23.2	0.0	0.0	0.0	0.0	0.0	0.0	7.4	4.2	10.6
Disability-free Multimorbidity	4.5	1.2	7.8	6.1	1.7	10.5	18.6	13.2	24.0	0.0	0.0	0.0	10.0	6.1	13.9
Disabling Multimorbidity	3.9	0.4	7.4	5.2	0.8	9.7	8.3	2.4	14.2	20.1	10.2	30.0	7.6	2.4	12.7
Total	28.4	22.4	34.4	28.2	22.1	34.3	26.9	20.0	33.8	20.1	10.2	30.0	26.9	20.4	33.4

HRS

Males

	Initial state														
Target State	0 disease	95% CI		1 disease	95% CI		Disability-free Multimorbidity	95% CI		Disabling Multimorbidity	95% CI		Average	95% CI	
0 disease	8.1	7.6	8.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	1.3	1.5
1 disease	5.6	5.3	5.9	8.3	7.9	8.7	0.0	0.0	0.0	0.0	0.0	0.0	3.2	3.0	3.3
Disability-free Multimorbidity	7.3	7.0	7.7	10.7	10.4	11.1	17.3	16.9	17.8	0.0	0.0	0.0	11.9	11.6	12.2
Disabling Multimorbidity	2.3	2.2	2.5	3.1	2.9	3.3	3.7	3.5	4.0	13.0	12.3	13.6	4.4	4.1	4.6
Total	23.4	23.0	23.7	22.1	21.8	22.5	21.1	20.7	21.5	13.0	12.3	13.6	20.8	20.5	21.2

Females

	Initial state														
Target State	0 disease	95% CI		1 disease	95% CI		Disability-free Multimorbidity	95% CI		Disabling Multimorbidity	95% CI		Average	95% CI	
0 disease	9.1	8.6	9.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	1.2	1.4
1 disease	6.8	6.4	7.1	9.0	8.6	9.4	0.0	0.0	0.0	0.0	0.0	0.0	3.3	3.1	3.4
Disability-free Multimorbidity	6.8	6.5	7.2	10.4	10.1	10.8	16.9	16.5	17.3	0.0	0.0	0.0	11.1	10.9	11.4
Disabling Multimorbidity	3.9	3.7	4.1	5.4	5.1	5.6	6.6	6.3	6.9	16.2	15.6	16.8	7.4	7.2	7.7
Total	26.6	26.2	26.9	24.8	24.5	25.1	23.5	23.2	23.9	16.2	15.6	16.8	23.1	22.8	23.4

Males - Primary education

	Initial state														
Target State	0 disease	95% CI		1 disease	95% CI		Disability-free Multimorbidity	95% CI		Disabling Multimorbidity	95% CI		Average	95% CI	
0 disease	8.6	6.5	10.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5	1.1	1.9
1 disease	4.9	3.9	6.0	7.7	6.5	9.0	0.0	0.0	0.0	0.0	0.0	0.0	2.9	2.4	3.4
Disability-free Multimorbidity	5.6	4.6	6.6	8.5	7.3	9.7	14.2	12.9	15.4	0.0	0.0	0.0	9.6	8.6	10.5
Disabling Multimorbidity	3.6	2.7	4.5	5.0	4.0	6.0	6.0	4.9	7.2	15.3	13.7	16.9	6.4	5.3	7.4
Total	22.7	21.4	23.9	21.2	20.1	22.3	20.2	19.0	21.4	15.3	13.7	16.9	20.3	19.3	21.4

Males - Secondary education

	Initial state														
Target State	0 disease	95% CI		1 disease	95% CI		Disability-free Multimorbidity	95% CI		Disabling Multimorbidity	95% CI		Average	95% CI	
0 disease	7.5	6.8	8.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	1.2	1.5
1 disease	5.4	4.9	5.8	8.0	7.5	8.5	0.0	0.0	0.0	0.0	0.0	0.0	3.1	2.9	3.3
Disability-free Multimorbidity	6.8	6.3	7.3	9.8	9.3	10.3	16.0	15.5	16.6	0.0	0.0	0.0	10.9	10.5	11.3
Disabling Multimorbidity	2.4	2.1	2.6	3.1	2.9	3.4	3.8	3.5	4.1	12.5	11.8	13.2	4.4	4.1	4.7
Total	22.1	21.5	22.6	20.9	20.5	21.4	19.9	19.4	20.4	12.5	11.8	13.2	19.7	19.3	20.1

Males - Post-secondary education

	Initial state														
Target State	0 disease	95% CI		1 disease	95% CI		Disability-free Multimorbidity	95% CI		Disabling Multimorbidity	95% CI		Average	95% CI	
0 disease	8.4	7.7	9.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5	1.4	1.6
1 disease	5.9	5.4	6.4	8.5	8.0	9.1	0.0	0.0	0.0	0.0	0.0	0.0	3.3	3.1	3.5
Disability-free Multimorbidity	8.3	7.7	8.8	12.1	11.5	12.7	19.0	18.4	19.6	0.0	0.0	0.0	13.1	12.7	13.6
Disabling Multimorbidity	2.2	1.9	2.4	2.9	2.6	3.1	3.5	3.1	3.8	13.1	12.3	13.9	4.2	3.8	4.5
Total	24.8	24.2	25.3	23.5	23.0	24.0	22.5	21.9	23.0	13.1	12.3	13.9	22.1	21.6	22.6

Females - Primary education

	Initial state														
Target State	0 disease	95% CI		1 disease	95% CI		Disability-free Multimorbidity	95% CI		Disabling Multimorbidity	95% CI		Average	95% CI	
0 disease	5.3	3.6	7.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.5	1.0
1 disease	6.0	4.6	7.3	7.5	6.0	8.9	0.0	0.0	0.0	0.0	0.0	0.0	2.8	2.2	3.3
Disability-free Multimorbidity	5.7	4.5	6.9	7.3	6.0	8.5	12.2	10.8	13.5	0.0	0.0	0.0	8.1	7.0	9.1
Disabling Multimorbidity	7.8	6.6	9.0	9.4	8.2	10.5	11.1	9.8	12.4	19.7	18.4	21.1	11.6	10.4	12.8
Total	24.8	23.5	26.0	24.1	23.0	25.3	23.3	22.1	24.5	19.7	18.4	21.1	23.2	22.0	24.3

Females - Secondary education

	Initial state														
Target State	0 disease	95% CI		1 disease	95% CI		Disability-free Multimorbidity	95% CI		Disabling Multimorbidity	95% CI		Average	95% CI	
0 disease	8.6	7.8	9.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	1.1	1.3
1 disease	6.7	6.2	7.1	8.8	8.3	9.4	0.0	0.0	0.0	0.0	0.0	0.0	3.2	3.0	3.4
Disability-free Multimorbidity	6.6	6.1	7.0	9.8	9.4	10.2	16.1	15.6	16.6	0.0	0.0	0.0	10.6	10.2	10.9
Disabling Multimorbidity	3.9	3.6	4.2	5.3	5.0	5.6	6.6	6.2	6.9	15.7	15.1	16.3	7.3	7.0	7.7
Total	25.7	25.3	26.2	24.0	23.6	24.4	22.7	22.3	23.1	15.7	15.1	16.3	22.3	22.0	22.7

Females - Post-secondary education

	Initial state														
Target State	0 disease	95% CI		1 disease	95% CI		Disability-free Multimorbidity	95% CI		Disabling Multimorbidity	95% CI		Average	95% CI	
0 disease	9.9	9.1	10.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	1.3	1.5
1 disease	7.0	6.5	7.5	9.3	8.7	9.8	0.0	0.0	0.0	0.0	0.0	0.0	3.4	3.2	3.6
Disability-free Multimorbidity	7.4	6.9	8.0	11.6	11.1	12.2	18.5	17.9	19.1	0.0	0.0	0.0	12.2	11.8	12.6
Disabling Multimorbidity	3.6	3.2	3.9	5.0	4.7	5.4	6.2	5.8	6.6	16.4	15.6	17.2	7.2	6.7	7.6
Total	27.9	27.4	28.4	25.9	25.5	26.4	24.7	24.2	25.2	16.4	15.6	17.2	24.1	23.7	24.6

Appendix III: Life expectancy comparison with vital statistics and other studies

Data source	Index	Year	Men			Women		
			Costa Rica	Mexico	United States	Costa Rica	Mexico	United States
Our study	LE60	2005-2009	24.3			25.1		
	(95% CI)		(22.9-25.8)			(23.3-26.9)		
		2012-2018		22.9			25.4	
				(21.8-24.0)			(24.4-26.3)	
		2004-2018			20.8			23.1
					(20.5-21.2)			(22.8-23.4)
Vital statistics								
World Health Organization (2020)	LE60	2005	22.4	20.3	20.6	25.2	22.7	23.4
		2010	22.5	20.3	21.5	25.4	22.7	24.2
		2015	23.3	20.4	21.7	26.4	22.9	24.4
United Nations Population Division (2022)	LE60	2005	21.3	20.0	20.6	24.0	22.3	23.7
		2010	21.3	19.7	21.6	24.1	22.1	24.6
		2015	21.2	19.7	21.9	24.3	22.3	24.8
Other studies								
Payne (2015)	LE65	2001-2003		18.4			19.2	
	(95% CI)			(16.3-20.7)			(17.4-21.5)	
		2005-2009	19.0			20.1		
			(17.8-20.8)			(18.8-21.9)		
		2004-2010			18.1			20.5
					(17.7-18.6)			(20.1-20.9)
Mehta & Myrskylä (2017)	LE50	1998-2012			27.7			31.4
					(26.9-29.0)			(30.7-32.5)
Rosero-Bixby (2018)	LE60	2002-2011		21.9			23.4	
	(95% CI)			(20.5-21.8)			(22.8-24.0)	
		2002-2012	21.9			24.3		
			(21.5-22.2)			(23.9-24.8)		
Rueda-Salazar (2021)	LE60	2005-2007	22.9			26.2		
	(95% CI)		(17.9-26.4)			(21.4-30.0)		

(Mehta & Myrskylä, 2017; Payne, 2018; Rosero-Bixby, 2018; Rueda-Salazar et al., 2021; United Nations Population Division, Department of Economic and Social Affairs, 2022; World Health Organization, 2020)

Appendix IV: Evidence for cumulative (dis)advantage

Difference in multimorbid life expectancy by education and gender in Costa Rica, Mexico, and the United States. Low educated indicates an educational attainment of primary school or less, and high educated indicates an educational attainment of post-secondary school.

	Low-educated			High-educated		
Country	Female	Male	Difference (Female MMLE – Male MMLE)	Female	Male	Difference (Female MMLE – Male MMLE)
Costa Rica	15.6	11.5	4.1	11.6	16.8	-5.2
Mexico	17.2	11.3	5.9	17.6	12.0	5.6
United States	19.7	16.0	3.7	19.4	17.3	2.1

MMLE: Multimorbid life expectancy

Appendix V: Sensitivity analysis excluding hypertension

Country	Gender	Target state	Sensitivity analysis average expectancy	Lower 95% CI	Upper 95% CI	Main analysis average expectancy	Difference between sensitivity and main expectancies
Costa Rica	Male	0 disease	10.9	10	11.7	6.2	-4.7
		1 disease	8.7	7.9	9.5	6.6	-2.1
		Disability-free multimorbidity	2.5	1.8	3.2	6	3.5
		Disabling multimorbidity	2.8	1.8	3.8	5.5	2.7
		Non-MMLE	19.6	17.9	21.2	12.8	-6.8
		MMLE	5.3	3.6	7	11.5	6.2
		Total life expectancy	24.8	23.6	26	24.3	-0.5
	Female	0 disease	7.5	6.7	8.3	2.5	-5
		1 disease	9.3	8.3	10.3	7.5	-1.8
		Disability-free multimorbidity	3.1	2.4	3.7	6.6	3.5
		Disabling multimorbidity	5.8	4.7	7	8.6	2.8
		Non-MMLE	16.8	15	18.6	10	-6.8
		MMLE	8.9	7.1	10.7	15.2	6.3
		Total life expectancy	25.6	24	27.2	25.1	-0.5
Mexico	Male	0 disease	8.9	8	9.7	4.9	-4
		1 disease	8.2	7.4	9	6.6	-1.6
		Disability-free multimorbidity	2.8	2.3	3.3	7	4.2
		Disabling multimorbidity	2.9	2.2	3.7	4.4	1.5
		Non-MMLE	17.1	15.4	18.7	11.5	-5.6
		MMLE	5.7	4.5	7	11.4	5.7
		Total life expectancy	22.8	21.8	23.9	22.9	0.1
	Female	0 disease	6.2	5.7	6.7	2.5	-3.7
		1 disease	8.9	8.3	9.5	5.6	-3.3
		Disability-free multimorbidity	4.7	4.1	5.2	9.3	4.6
		Disabling multimorbidity	5.5	4.6	6.3	7.9	2.4
		Non-MMLE	15.1	14	16.2	8.1	-7
		MMLE	10.2	8.7	11.5	17.2	7
		Total life expectancy	25.3	24.3	26.3	25.4	0.1
United States	Male	0 disease	2.9	2.8	3.1	1.4	-1.5
		1 disease	5.2	5	5.4	3.2	-2
		Disability-free multimorbidity	8.8	8.5	9.1	11.9	3.1
		Disabling multimorbidity	3.9	3.7	4.1	4.4	0.5
		Non-MMLE	8.1	7.8	8.5	4.6	-3.5
		MMLE	12.7	12.2	13.2	16.3	3.6
		Total life expectancy	20.8	20.5	21.1	20.8	0
	Female	0 disease	2.4	2.3	2.5	1.3	-1.1
		1 disease	6.3	6.1	6.5	3.3	-3
		Disability-free multimorbidity	8	7.7	8.2	11.1	3.1
		Disabling multimorbidity	6.5	6.2	6.7	7.4	0.9
		Non-MMLE	8.7	8.4	9	4.6	-4.1
		MMLE	14.5	13.9	14.9	18.5	4
		Total life expectancy	23.1	22.8	23.4	23.1	0