Received: 24 June 2020 | Revised: 5 February 2021 | Accepted: 21 February 2021

DOI: 10.1002/hec.4258

SPECIAL ISSUE PAPER

Health Economics WILEY

The future of the elderly population health status: Filling a knowledge gap

Vincenzo Atella[1] | **Federico Belotti**[1] | **Daejung Kim**[2] | **Dana Goldman**[3] | **Tadeja Gracner**[4] | **Andrea Piano Mortari**[5] | **Bryan Tysinger**[6]

[1]Department of Economics and Finance, University of Rome "Tor Vergata", Rome, Italy

[2]Korea Institute for Health and Social Affairs (KIHASA), Sejong City, South Korea

[3]University of Southern California, Los Angeles, California, USA

[4]RAND Corporation, Arlington, Virginia, USA

[5]Centre for Economic and International Studies. University of Rome "Tor Vergata", Rome, Italy

[6]Sol Price School of Public Policy, University of Southern California, Los Angeles, California, USA

Correspondence
Federico Belotti, Department of Economics and Finance, University of Rome "Tor Vergata", Via Columbia, 2-00133, Rome, Italy.
Email: federico.belotti@uniroma2.it

Abstract

The aging process in OECD countries calls for a better understanding of the future disease prevalence, life expectancy (LE) and patterns of inequalities in health outcomes. In this paper we present the results obtained from several dynamic microsimulation models of the Future Elderly Model family for 12 OECD countries, with the aim of reproducing for the first time comparable long-term projections in individual health status across OECD countries. We provide projections of LE and prevalence of major chronic conditions and disabilities, overall, by gender and by education. We find that the prevalence of main chronic conditions in Europe is catching-up with the United States and significant heterogeneity in the evolution of gender and educational gradients. Our findings represent a contribution to support policymakers in designing and implementing effective interventions in the healthcare sector.

KEYWORDS

disease burden, education gradient, gender gap, health care demand, microsimulation, OECD, population aging

1 | INTRODUCTION

The impact of aging population represents a serious concern for many countries around the world. On average, across the OECD in 1980 there were only 20 people aged 65 and over for every 100 in working-age; by 2015 this number had risen to 28 and by 2050 is projected to almost double to reach 53 people according to OECD (2017). This phenomenon will be particularly severe in Europe where, according to the long-term demographic trends of the European Commission (EC, 2015), the population will be turning "increasingly gray" in the upcoming decades. The latest official EU estimates confirm that the median age in 2060 is projected to reach 45 years for males and 47 years for females, representing, respectively, an upward shift of 12.5% and 4.6% with respect to 2013 (EC, 2015).

Increasing life expectancy (LE), along with declining fertility rates and the dynamics of migration flows, are the key ingredients of the current aging process in several OECD countries (Cutler & Meara, 2004). Since the end of WWII economic development has contributed to substantially improve environmental conditions and lifestyles, and to achieve enormous progress in health and medicine. In particular, medical technologies are among the main determinants for the increase in LE: they have turned many, once deadly, diseases into chronic conditions (Atella et al., 2017; Klenk et al., 2016; Mathers et al., 2015; OECD, 2016a, 2016b). It is a well-established fact that women, on average, live longer

than men (Luy, 2003). The size of the excess LE is not homogeneous nor constant. In OECD countries, it increased in the period 1950–1970, declined afterward and nowadays amounts to about 4–5 years in the richest countries (Oksuzyan et al., 2000). Similarly, better educated individuals are, on average, healthier and live longer than less educated ones. According to Meara et al. (2008) in the year 1990, US Americans aged 25 with any college education lived, on average, more than 5 years longer compared to those with less than a high school education. By the year 2000, the gap increased to 7 or more years. A similar gradient has been observed in many other countries (Cutler et al., 2008; Grossman, 2006).

According to Bardi and Pierini (2013) and Van Oyen et al. (2013), since 2003 many European countries have witnessed a significant decline in healthy LE at birth, inverting what had been a long-term trend. This decline has been particularly marked in Europe, with significant differences across geographical areas and across gender: women tend to live longer, but spend more years in bad health with respect to men.[1] Similarly, recent work in United States by Case and Deaton (2015, 2017) has shown "increases in mortality and morbidity among White non-Hispanic Americans in midlife since the turn of the century, while all-cause mortality continued to increase unabated to 2015, with additional increases in drug overdoses, suicides, and alcohol-related liver mortality, particularly among those with a high-school degree or less. The decline in mortality from heart disease has slowed and, most recently, stopped, and this combined with the three other causes is responsible for the increase in all-cause mortality." These trends well describe the substantial heterogeneity in health, even in high-income countries. A comparison in terms of the prevalence of severe chronic conditions between the elderly population in United States and England can be found in Banks et al. (2006). They find that a gradient in the health status exists at all points of the socioeconomic status (SES) distribution, with the US residents being less healthy than their English counterpart. Differently, Solé-Auró et al. (2015) do not find any significant differences in the incidence of chronic conditions and mortality between five European countries and United States after controlling for SES and differences in the distribution of risk factors.

Given this evidence and ongoing trends, an accurate forecast of the future health status of the population could offer an important support to policy makers to design and implement effective and sustainable policies. According to Foreman et al. (2018), past work on forecasting has provided an incomplete landscape of future health scenarios, highlighting a need for a more robust modeling platform from which policy options and potential health trajectories can be assessed. In fact, in spite of the existence of several reliable models predicting the population structure by age and sex in the long-term (United Nations [UN], 2015a, 2015b, 2015c), models allowing forecasting population long-term health status at individual level are rare, such as those in the United States (Goldman et al., 2013) and United Kingdom (Guzman-Castillo et al., 2017). More recently, Foreman et al. (2018) has developed a model based on aggregated data from Global Burden of Disease (GBD) 2016 study to systematically account for the relationships between risk factors and health outcomes for 79 independent drivers of health using GBD 2016 estimates from 1990 to 2016, to generate predictions for 2017–40 in 195 countries and territories. Concerning Europe, the only tool available to policymakers is the one implemented by the Ageing Working Group (AWG) of the European Commission (EC, 2015), which predicts long-term trends in social security expenditure based on predictions of GDP rather than estimates of the health status of the population.[2] Much less is available in other OECD countries. In this context, the availability of a reliable quantitative tool able to assess the impact of future demographic and epidemiological changes on population health status and healthcare demand, and on governments' budget, is crucial.

Fulfilling this task requires a huge effort in data harmonization and sophisticated and complex modeling methods that take the evolution of health, economic, and demographic variables at individual and cohort levels into account. Microsimulation models have emerged as a useful tool to answer these questions (Astolfi et al., 2011, 2012). Among this class of models, the Future Elderly Model (FEM; Goldman et al., 2005), based on the Health and Retirement Study (HRS) data, has been extensively used to explore a variety of policy questions over the last decade in the United States.[3] More recently, modified versions of FEM have been employed also in other countries (see Chen et al., 2016; Gonzalez-Gonzalez et al., 2017; Kasajima et al., 2020; Kim et al., 2019). Furthermore, FEM has been exploited to study the impact on public finance of the differences in health between Americans and Western European (Michaud et al., 2011).

In this study, we present novel results obtained from combining the US FEM with different FEM-like models for Europe (EU-FEM), South Korea (FEM-Korea), and Mexico (FEM-Mexico).[4] The FEM is a multirisk and multimorbidity state-transition dynamic microsimulation model for projecting the health status of the population by aggregating the projections at individual level.[5] The FEM accounts for the multidimensional nature of health status through a first-order Markov process in which static and time-varying characteristics at time t impact health outcomes at time $t + 1$. This allows a reliable estimation of the transitional dynamics of several outcomes (e.g., demographic indicators, health outcomes, risk factors, health expenditure, and other socioeconomic outcomes). The wide set of internal and external model validations show that FEM provides a reliable representation of the future disease burden for

the population aged 50 and older. As such, this study offers an important contribution in shedding light on the future needs of aging populations and in supporting policy makers to tackle the future societal challenges.

The remainder of the paper is as follows. In Section 2 we briefly describe the current health status for the 13 countries under examination, highlighting the main changes occurred in the last 25 years in terms of death rates and years lived with disabilities, focusing on the morbidity of specific diseases and on the main risk factors affecting the population. Section 3 briefly introduces the model. Section 4 describes the data employed to obtain the simulations, while Section 5 presents the results. Finally, Section 6 offers some concluding remarks.

2 | HEALTH CONDITIONS IN OECD COUNTRIES

According to the OECD (2019), LE across OECD partners increased by over 10 years between 1970 and 2017, with an average of 2.6 months a year. The gains obtained in longevity can be attributed to a number of factors including improved lifestyles, better education, and progress in health care. However, the gap between the longest—(Japan) and the shortest—(South Africa) living countries remains almost unchanged, amounting to about 20 years. Moreover, on average women tend to live about 5.3 years longer than men, but this gender gap narrows to 1 year if healthy life years are considered. Finally, there are large gaps in LE by education level (about 6 years between low and high educated individuals).

Avoidable deaths constitute another serious problem in OECD countries, with the main causes of death represented by circulatory diseases, cancer, and respiratory diseases, and all of them are preventable. The prevalence of chronic diseases such as diabetes is rising, particularly due to rising rates of obesity. Dementia prevalence has increased as well and will continue to rise, due to population aging: among the 80+ population the number of diagnosed patients increased from 1 million in 1995 to 2 million in 2015, and is expected to exceed 3 million by 2030.

These patterns are likely driven by different factors such as heterogeneous changes in SES by age groups, lifestyle changes and less healthy environment. In particular, concerning lifestyle changes, while tobacco smoking has declined across European countries, still more than one-fifth of adults smoke every day, with rates that are highest in Greece and Hungary. Among adolescents, 12% smoke weekly. Alcohol consumption in the OECD averaged 9 L of pure alcohol per person per year, equivalent to almost 100 bottles of wine. This figure is driven by the sizeable share of heavy drinkers: about 30% of men and 12% of women binge-drink at least once per month. More than one-fifth of adults report regular heavy alcohol drinking (about 33% of men and 14% of women). With respect to adolescents 22% reports having been drunk at least twice in their lives. Finally, since the late 1990s, obesity has risen quickly in many OECD countries, and more than doubled in South Korea and Norway, albeit from low levels. Self-reported obesity has gone up among 15-year-olds from 11% in 2001–2002 to 17% in 2013–2014 and among adults has increased from 11% in 2000 to over 15% in 2014. Overall, 54% of adults in OECD countries today are overweight, including 19% who are obese. Obesity rates are higher than 30% in Hungary, Mexico, New Zealand, and the United States. Even worse is the share of adolescent who are obese or overweight: among 15-year olds, 25% are overweight and only 15% do enough physical activity.

With respect to environmental risk exposure, the World Health Organization (WHO) estimates that overall, 92% of the world's population is breathing air above the PM2.5 guidelines (Donaldson & Rutter, 2017), and indoor and outdoor air pollution cause approximately 7 million premature deaths per year (WHO, 2014). In 21 OECD countries, over 90% of people are exposed to unsafe levels of air pollution. Furthermore, according to the European Environment Agency (EEA), at least since 1997 a relevant fraction of the European urban population (ranging from 13% to 62% according to country) has been exposed to concentrations of particulate matter (PM10) above the limit imposed by the EU for the human health protection (EEA, 2018). OECD projections estimate that outdoor air pollution will cause 6–9 million premature deaths by 2060, and cost 1% of global gross domestic product (GDP) (OECD, 2016a, 2016b). Also, todays populations are increasingly exposed to chemical agents and highly processed foods, which foster the insurgence of chronic diseases such as diabetes, hypertension, cardiac disease, obesity, and various cancers (Mattson et al., 2014). The interactions between the environment, lifestyle, and health in determining the risks of chronic cardiovascular and metabolic diseases are at the main focus of the EU Commission research agenda (Ronkainen et al., 2021).

Nowadays, the heterogeneity in healthy aging as a function of SES, gender and education is substantial, and being able to account for heterogeneous trajectories of chronic diseases is particularly important from a policy perspective.

3 | THE FEM FRAMEWORK

The FEM is a dynamic microsimulation model designed to project the future costs and health status of the elderly based on their current health status, taking into account a broad set of risk factors. In contrast to existing projection models that use aggregate measures of health traits for population groups, the FEM simulates at the individual level exploiting longitudinal survey data, thus allowing for larger heterogeneity compared to cell-based approaches (Li & O'Donoghue, 2013). Furthermore, this heterogeneity allows for the implementation of detailed interventions altering the way in which people access health care or benefit from technological advancements.

For all countries, we consider the same model structure consisting of four key components: (i) the initial population, (ii) the transition module, (iii) the replenishing cohort module, and (iv) the policy outcomes module. A schematic overview of the model is provided in Figure 1. The model starts at time t with an initial population of 50+ individuals, which transits at time $t + 2$ thanks to the transition module.[6] The latter ages individuals and exploits a first-order Markov approach to assign each outcome based on the individual characteristics in the previous wave of the simulation (see Table 1 for a summary of the transitioned outcomes by types).[7] Tables E.1–E.7 report the estimated marginal effects at means from the chronic conditions and mortality transition models. To better take into account country heterogeneity the mortality model in EU-FEM has been estimated at country level.[8] In general, the sign of the effects is in line with expectations, with incidence increasing in age and risk factors (smoking habits and body mass index [BMI]) and decreasing in education. Men have a higher incidence compared to women and having any of the considered conditions at age 50 is always detrimental. Closer inspection of Table E.4 shows a protective effect of education against heart disease in the United States, something absent in other countries. It is worth noting the strong effect of disabilities in increasing significantly the probability of dying in all countries (Table E.7).

Going back to the model structure, the replenishing cohort module fills up the 50–51 and 51–52-year-old individuals at time $t + 2$ in order to maintain the 50+ population structure at each simulation step. The survey data weights of the entering cohorts are rebalanced to match official population estimates and projections by country, year, age, and sex. For US cohorts, the population estimates and projections are further broken down by race/ethnicity based on the US Census Bureau population estimates and projections. For European countries, the weights are also rebalanced by year, sex, and educational attainment to match the International Institute for Applied Systems Analysis and Vienna Institute of Demography (IIASA/VID) estimates and projections of past and future educational attainment. The European cohorts are reweighted exactly to the proportion of the cohort in each level of educational attainment in the IIASA/VID data. The US cohort creation process uses the trends rather than absolute level because the ISCED levels used by IIASA/VID do not match exactly with the educational attainment categories in the HRS.

To forecast the health status of the future 50–52 years old population, we model the marginal distribution of each outcome allowing for correlation across these marginals. The correlations are assumed fixed while the mean of the marginals is allowed to change over time according to country-specific health, risks and SES trends, coming from different sources (see Section 4). Both the mean and the correlation matrix across marginals are estimated using a multivariate conditional mixed process model (Roodman, 2011). Finally, the policy module summarizes individual-level outcomes to produce the output of interest, such as disease prevalences and LE.

3.1 | Internal validation

An internal validation exercise comparing simulated with observed prevalences of chronic conditions by gender and education is reported in Figures G.1–I.5 for EU-FEM, FEM, and FEM-Korea. Overall the performance of the models are satisfactory, with the projections being able to replicate both the actual levels and trajectories with the exceptions of US population with less than high school and the trends of hypertension among the South Korea population of higher educated. As for Mexico, the first row of Table D.1 presents prevalences as recorded in the Mexican Health and Aging Study (MHAS), the second row as estimated using the FEM-Mexico, while the third as estimated using the calibrated model. A comparison between the first two rows highlights a relatively small difference between forecasted and actual average BMI, prevalence in overweight, obesity, having any difficulties with ADL, and stroke. However, the model overestimates the prevalence of self-reported diabetes (28.4% compared to an actual 23.9%), of heart attack (11.9% compared to an actual 5.5%), as well as of high blood pressure or hypertension (64.4% compared to an actual 50.5%). To this end, we calibrated the model to obtain comparable estimates (third row). We then used these calibrated transition models for the final simulations presented in this study.

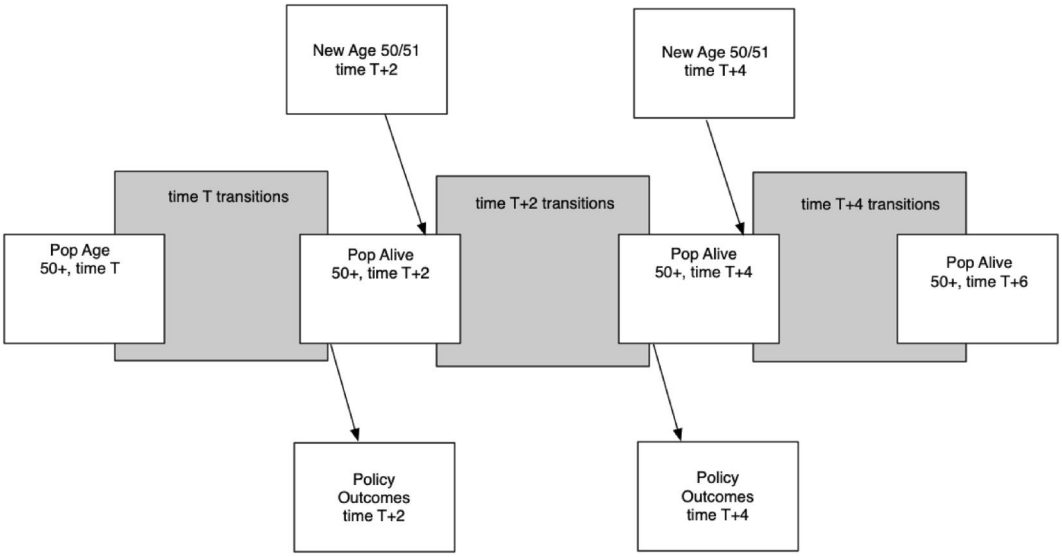

FIGURE 1 The "FEM-like" model flow. FEM, Future Elderly Model

TABLE 1 Estimated outcomes

Variable	Type of variable	Type of model	Transition timing
Mortality	Binary	Probit	Absorbing
Life expectancy at 65	Continuous	Computed	Every wave until death
Disability free life expectancy at 65	Continuous	Computed	Every wave until death
Chronic diseases			
Cancer	Binary	Probit	Absorbing
Diabetes	Binary	Probit	Absorbing
Heart disease	Binary	Probit	Absorbing
Hypertension	Binary	Probit	Absorbing
Chronic lung disease	Binary	Probit	Absorbing
Stroke	Binary	Probit	Absorbing
At least one chronic disease	Count	Poisson	Every wave
Functional limitations			
Number of difficulties with ADLs	Ordered	Ordered probit	Every wave
Number of difficulties with iADLs	Ordered	Ordered probit	Every wave

Abbreviations: ADL, activities of daily living; iADL, instrumental activities of daily living.

4 | DATA AND SUMMARY STATISTICS

Microsimulation models require a large amount of data in order to reliably reproduce the heterogeneity of the target population. They are typically based on sample surveys or administrative data containing a set of variables describing demographic, health, labor force, income, and other characteristics of each unit. In order to build these models various data sources are often merged, with the FEM-type models being fairly unique in their reliance on detailed panel surveys that feature information on health risk factors, health conditions, functional limitations, mortality, and health-related economic outcomes. In this section, we briefly refer to the main source of data used for each country model. The HRS, as well as all other HRS family surveys used in this work (the Survey of Health, Ageing and Retirement in Europe [SHARE], MHAS, and the Korean Longitudinal Study of Aging [KLoSA]) allows to explore topics related to work, retirement, work quality, health, health care, psychological factors, aspects of daily life, and socioeconomic positions

among people aged 50 and over. The data were collected using computer-assisted personal interviews supplemented by self-completed paper-and-pencil questionnaires. All models in this study are fed by the harmonized version of the aforementioned surveys developed by the Gateway to Global Aging Data project. The latter aims at harmonizing survey data on aging around the world with the RAND HRS data, thus greatly simplifying the adaptation of the FEM to other countries and allowing for meaningful comparison of the results.[9] Nevertheless, some issues remains, for example, regarding question wording and disputed answers. As for the former, a thoughtful discussion can be found in Solé-Auró et al. (2015). Regarding the latter, in HRS all conditions can be disputed, in SHARE only cancer, heart diseases and stroke records can be disputed whereas no dispute is allowed in KLoSA and MHAS. In any case, the coherence of the longitudinal information is ensured by the harmonization process since, when allowed, disputes of previous records are fed back to correct them.

Concerning the SHARE survey, it includes data from a large number of European countries, but due to limits in data availability over time only nine European countries have been considered in EU-FEM. The current version of EU-FEM is based on an unbalanced panel sample of 101,176 observations (47,629 individuals included in at least two of the six considered SHARE waves).[10] It is worth noting that, due to the fact that institutionalized individuals are missing in the sample, SHARE might suffer from underestimation of real mortality. Nevertheless, as suggested by the small differences between the EU-FEM and the UN population projections reported in Figure G.6, this issue does not seem to affect substantially our projections. This is reassuring and in line with the performance of the FEM. In order to generate future replenishing cohorts, these data are supplemented with historical trends for BMI and smoking status at the country level extracted from the European Community Households Panel (ECHP) survey, while chronic disease prevalences have been trended using the Italian HS-SISSi database, under the assumption that the Italian population epidemiological trends (not the levels) are applicable to the other European countries.[11]

Korean data are from the KLoSA, a longitudinal study of individuals over age 45 in the Republic of Korea. We used the harmonized KLoSA dataset which contains Waves 1, 2, 3, and 4 as of October 2015. The KLoSA data are used to compute the health transition models that comprise the core of the FEM-Korea, as well as to provide the characteristics of the starting population for the simulations. Replenishing cohorts in the Korean FEM match projections by birth cohort and educational attainment.

Mexican individual level data comes from the MHAS, a prospective survey of a nationally and urban/rural representative sample of adults aged 50 years and older residing in Mexico in 2001, 2003, and 2012. A refresher sample of individuals aged 50–61 was added in 2012, to recover the representativeness of population aged 50 and older. As for the other datasets, the MHAS includes health in multiple domains, health behaviors and risk factors, socioeconomic conditions, work history, health insurance, health expenditures, and family background, among others. The MHAS differs from HRS in one important aspect: the interwave periods. As mentioned above, the FEM is built around HRS which is collected every 2 years; MHAS has a 2-year gap between the first (2001) and second (2003) waves and a 9-year gap between the second and third (2012). To overcome this issue, we use the first two waves of MHAS to estimate biannual health transitions, and we use the third wave as the starting population. In other words, we imposed the 2001–2003 health transitions on the 2012 MHAS population. Regarding population projections, we compared FEM-Mexico projections to Consejo Nacional de Población (CONAPO) projections of the Mexican population, focusing on the 50+ population. For this exercise, we began the simulation in 2012 and simulated the full population through 2050. Mexican FEM population projections were then compared to the 2010 CONAPO projections for years 2012 through 2050. As shown in Table D.2, the difference between our projections and CONAPO's is less than 2% for both men and total population, while a deviation of 4 percentage points is obtained for women.

As already mentioned the HRS dataset is the main source for the FEM. This source has been supplemented with merged Social Security covered earnings histories and data on health trends and health care costs coming from three major health surveys in the United States (for more details on FEM data sources see National Academies of Sciences, Engineering, and Medicine, 2015, Appendix B).

Country-specific summary statistics for socioeconomic and health variables for the starting population (2014 for United States, Mexico, and South Korea; 2015 for European countries) are shown in Table 2 . All the starting populations are characterized by a larger women's share and by an average age higher than 65. South Korea has the least educated elderly population, followed by the United States and Mexico. With reference to chronic conditions the United States is characterized by the highest prevalence of any of the considered conditions except for diabetes, that is, more frequent in Mexico. As for risk factors, the United States show the highest share of severely obese, followed by Mexico, while South Korea displays the highest prevalence of nonobese people. Disabled elderly are more prevalent in the United States, both in terms of activities of daily living (ADL) and instrumental activities of daily living (iADL). As for

TABLE 2 Starting population

	Europe		United States		South Korea		Mexico	
Variable	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**
Male	0.45	0.498	0.445	0.497	0.429	0.495	0.433	0.495
Age	67.991	10.753	68.201	12.461	66.735	10.179	65.432	9.9
Less than high school	0.194	0.395	0.213	0.409	0.622	0.485	0.871	0.335
Some college and above	0.272	0.445	0.446	0.497	0.108	0.311	0.099	0.298
Hypertension	0.387	0.487	0.59	0.492	0.391	0.488	0.432	0.495
Diabetes	0.116	0.32	0.231	0.422	0.165	0.371	0.238	0.426
Cancer	0.071	0.258	0.161	0.367	0.049	0.216	0.031	0.175
Lung disease	0.076	0.265	0.114	0.318	0.031	0.174	0.092	0.288
Heart disease	0.165	0.371	0.262	0.44	0.081	0.273	0.044	0.206
Stroke	0.048	0.213	0.104	0.305	0.054	0.226	0.035	0.184
Ever smoked	0.505	0.5	0.587	0.492	0.307	0.461	0.11	0.313
Current smoking	0.178	0.383	0.154	0.361	0.16	0.367	0.234	0.423
BMI < 25	0.422	0.494	0.32	0.466	0.764	0.425	0.351	0.477
$25 \leq$ BMI < 30	0.406	0.491	0.358	0.48	0.223	0.416	0.42	0.494
BMI ≥ 30	0.171	0.377	0.322	0.467	0.013	0.115	0.229	0.42
No limitations (ADLs)	0.902	0.298	0.771	0.42	0.952	0.214	0.849	0.358
1 ADL	0.052	0.223	0.089	0.285	0.015	0.12	0.077	0.267
2 or more ADLs	0.046	0.209	0.14	0.347	0.034	0.18	0.074	0.262
No limitations (iADLs)	0.955	0.207	0.855	0.352	0.891	0.312	0.898	0.302
1 iADL	0.026	0.158	0.076	0.266	0.052	0.221	0.059	0.236
2 or more iADLs	0.019	0.138	0.068	0.252	0.058	0.233	0.042	0.201
Obs	32,857		20,666		7457		14,627	

Abbreviations: ADL, activities of daily living; BMI, body mass index; iADL, instrumental activities of daily living.

the (simulated) incoming cohorts, Table 3 reports summary statistics for selected years (2020, 2035, and 2050). All models are characterized by a relatively stable prevalence of chronic conditions with the exception of a 2 percentage points increase for hypertension in United States and European countries. With reference to risk factors, trends in smoking habits are decreasing in United States and European countries, stable in South Korea and slightly increasing in Mexico while, the prevalence of obese 50–52 population (BMI ≥ 30) is assumed to increase by 9% in United States and Europe and 3% in Mexico. Differently from United States and European countries, both Mexico and South Korea will experiment a substantial increase in the share of high educated individuals.

5 | PROJECTIONS THROUGH 2050

In this section, we present the simulation results at 2050 for a large set of health indicators: LE at 65 years, prevalence rates for cancers, diabetes, heart diseases, hypertension, lung diseases, stroke, presence of at least one chronic condition, and disability (defined as any ADL or iADL). Results are presented for South Korea, Mexico, United States, and for the pooled nine European countries. All results have been obtained under the assumption that the outcome drivers follow past trends and no intervention is planned in the future. In addition, given the common model structure and data collection and harmonization processes, all cross-country differences should be interpreted as being driven by population health heterogeneities and not as results of data and/or model specification/estimation differences. We also take

TABLE 3 Trends in replenishing cohorts

	Europe			United States			South Korea			Mexico		
	2020	2035	2050	2020	2035	2050	2020	2035	2050	2020	2035	2050
Age	50.68	50.68	50.68	51.98	51.98	51.99	51.50	51.50	51.50	50.49	50.49	50.50
Male	0.50	0.49	0.50	0.49	0.50	0.51	0.51	0.51	0.51	0.47	0.47	0.47
Less than high school	0.09	0.09	0.10	0.12	0.14	0.16	0.01	0.00	0.00	0.48	0.51	0.51
Some college and above	0.23	0.22	0.22	0.57	0.56	0.54	0.46	0.70	0.70	0.16	0.24	0.27
Cancer	0.02	0.03	0.03	0.06	0.05	0.05	0.02	0.02	0.02	0.01	0.01	0.01
Diabetes	0.05	0.05	0.05	0.12	0.14	0.15	0.05	0.05	0.05	0.04	0.04	0.04
Heart disease	0.05	0.05	0.06	0.09	0.09	0.09	0.02	0.03	0.03	0.01	0.01	0.01
Hypertension	0.22	0.24	0.24	0.40	0.41	0.42	0.15	0.16	0.16	0.17	0.17	0.17
Lung disease	0.02	0.02	0.01	0.05	0.05	0.05	0.00	0.00	0.00	0.04	0.04	0.04
Stroke	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00
Ever smoked	0.45	0.35	0.27	0.52	0.42	0.32	0.34	0.34	0.34	0.43	0.47	0.48
Current smoking	0.18	0.12	0.08	0.20	0.13	0.09	0.24	0.24	0.24	0.24	0.25	0.25
BMI < 25	0.42	0.40	0.38	0.22	0.20	0.18	0.79	0.79	0.79	0.34	0.36	0.40
$25 \leq$ BMI < 30	0.40	0.37	0.34	0.35	0.33	0.30	0.20	0.19	0.19	0.38	0.35	0.31
BMI ≥ 30	0.19	0.23	0.28	0.43	0.47	0.52	0.01	0.01	0.01	0.27	0.30	0.30
No limitations (ADLs)	0.96	0.96	0.96	0.86	0.85	0.84	1.00	0.99	0.99	0.93	0.94	0.95
1 ADL	0.03	0.02	0.03	0.07	0.08	0.08	0.00	0.00	0.00	0.06	0.05	0.04
2 ADLs*	0.01	0.01	0.00	0.04	0.03	0.03	0.00	0.00	0.00	0.01	0.01	0.01
3 or more ADLs	0.00	0.00	0.01	0.02	0.03	0.05	0.00	0.01	0.01	–	–	–
No limitations (iADLs)	0.98	0.98	0.98	0.92	0.91	0.91	0.97	0.97	0.97	0.98	0.98	0.98
1 iADL	0.00	0.00	0.00	0.06	0.07	0.08	0.03	0.02	0.02	0.02	0.02	0.02
2 or more iADLs	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.00	0.00	0.00

Note: Only variables common to all models are reported. "2 or more ADLs" for Mexico.

Abbreviations: ADL, activities of daily living; BMI, body mass index; iADL, instrumental activities of daily living.

into account the stochastic nature of the simulations and report 95% confidence intervals based on the standard deviation of the projected outcomes over Monte Carlo replications.[12]

In Table 4, we present the population aggregated results for selected years (2014, 2030, and 2050) and as absolute difference between 2050 and 2014 while, in Figures 2–10, we show for each outcome the dynamic of the simulated gender and education gradients by country. In this way, we can easily summarize and compare both levels and trends across countries and highlight any meaningful difference.

5.1 | LE at age 65 and disability

As we can see from Table 4, the models are able to replicate the ranking in levels across countries. South Korea and Mexico are the countries that are predicted to have the highest increase in LE at 65 until 2050 (around 4 years, on average), while no increase is expected in the United States. These values seem to be aligned with the most recent estimates obtained by Foreman et al. (2018), who foresee that LE at 65 will increase worldwide by 4.4 years for both men and women by 2040, although this average varies dramatically across the 195 countries and territories covered by their model (from 57.3 years in Lesotho to 85.8 years in Spain).

TABLE 4 .Main outcomes projections by country and selected years

Diseases	Countries	2014[a]	95% CI		2030[a]	95% CI		2050[a]	95% CI		Δ2050 − 2014[a]	95% CI	
Cancer	United States	14.8	14.4	15.2	19.3	18.6	19.9	20.5	19.8	21.1	6.7	6.0	7.3
	Europe	10.5	10.5	10.5	16.6	16.0	17.1	19.9	19.4	20.5	9.4	8.9	10.0
	South Korea	5.3	5.1	5.5	7.7	7.0	8.3	8.7	8.0	9.4	4.1	3.4	4.8
	Mexico	2.8	2.6	3.1	4.2	3.5	4.9	5.6	4.4	6.8	3.2	2.0	4.4
Diabetes	United States	22.5	22.1	22.9	30.7	30.0	31.4	35.7	35.0	36.4	15.0	14.3	15.7
	Europe	15.5	15.5	15.5	23.5	22.9	24.1	29.2	28.5	29.8	13.7	13.0	14.3
	South Korea	15.5	15.1	15.9	19.0	18.3	19.8	23.7	22.5	24.9	8.9	7.7	10.1
	Mexico	20.4	19.9	20.8	20.4	19.2	21.7	21.4	19.8	22.9	1.5	0.0	3.1
Heart disease	United States	23.3	22.8	23.8	30.0	29.3	30.7	32.4	31.7	33.1	10.3	9.6	10.9
	Europe	17.3	17.3	17.3	27.1	26.5	27.7	33.0	32.3	33.7	15.7	15.0	16.4
	South Korea	7.6	7.3	7.8	11.6	10.9	12.3	15.9	15.0	16.8	9.0	8.1	9.9
	Mexico	3.5	3.3	3.7	4.1	3.6	4.7	5.0	4.2	5.8	1.6	0.7	2.4
Hypertension	United States	58.1	57.6	58.6	66.5	65.8	67.2	69.3	68.6	70.0	13.8	13.1	14.5
	Europe	48.5	48.5	48.5	63.0	62.4	63.6	68.7	68.2	69.2	20.1	19.7	20.6
	South Korea	36.4	35.9	36.8	44.5	43.7	45.2	51.5	50.4	52.6	16.6	15.5	17.7
	Mexico	36.7	35.9	37.5	42.5	40.6	44.3	46.3	44.6	47.9	11.6	10.0	13.3
Lung disease	United States	10.1	9.8	10.4	12.4	12.0	12.9	12.2	11.7	12.6	2.8	2.4	3.3
	Europe	10.4	10.4	10.4	18.6	18.0	19.1	22.6	22.1	23.2	12.3	11.7	12.8
	South Korea	2.8	2.6	3.0	4.1	3.7	4.4	5.7	5.2	6.3	3.2	2.6	3.8
	Mexico	9.5	9.0	10.1	15.8	14.7	16.9	17.0	15.9	18.0	9.4	8.3	10.4
Stroke	United States	8.3	8.0	8.6	11.3	10.8	11.9	13.5	12.9	14.0	5.3	4.8	5.9
	Europe	6.5	6.5	6.5	11.7	11.2	12.2	15.2	14.7	15.8	8.7	8.2	9.3
	South Korea	5.2	4.9	5.4	7.9	7.3	8.4	11.5	10.6	12.3	6.9	6.0	7.7
	Mexico	3.2	3.0	3.4	3.7	3.2	4.3	4.0	3.3	4.8	1.2	0.4	2.0
At least	United States	73.7	73.2	74.2	81.7	81.2	82.2	82.9	82.4	83.4	12.5	12.0	13.0
One disease	Europe	63.6	63.6	63.6	77.0	76.5	77.5	80.8	80.4	81.2	17.2	16.8	17.6
	South Korea	49.6	49.0	50.1	60.0	59.0	60.9	67.7	66.6	68.8	20.4	19.3	21.5
	Mexico	51.6	50.5	52.7	59.4	57.6	61.1	62.6	61.0	64.1	14.5	12.9	16.1
Disabled	United States	23.8	23.2	24.5	27.4	26.7	28.2	32.1	31.4	32.8	9.1	8.4	9.8
	Europe	14.3	14.3	14.3	18.5	18.0	19.1	23.3	22.7	24.0	9.0	8.4	9.6
	South Korea	11.9	11.3	12.4	16.3	15.6	17.0	23.9	22.8	24.9	14.1	13.1	15.2
	Mexico	16.4	15.6	17.2	18.2	16.9	19.4	20.4	19.0	21.9	3.9	2.5	5.3
LE at 65	United States	18.6	17.4	19.9	18.7	17.5	19.8	19.5	18.2	20.8	0.8	−1.0	2.7
	Europe	21.8	21.4	22.2	22.4	21.2	23.6	24.2	23.6	24.9	2.4	1.6	3.2
	South Korea	22.9	21.8	24.0	25.1	23.6	26.5	26.8	24.7	28.9	3.9	1.3	6.5
	Mexico	15.7	14.1	17.3	17.5	14.5	20.5	19.9	16.8	22.9	4.1	0.6	7.7

Abbreviation: CI, confidence interval.

[a]For the nine European countries the years are 2015, 2031, 2051, and 2015–2051, respectively.

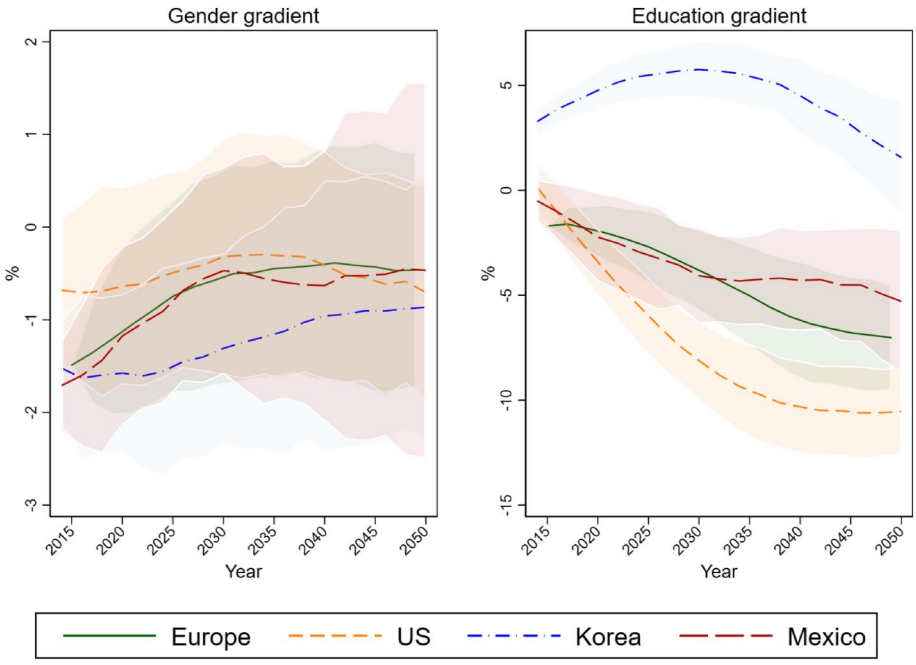

FIGURE 2 Projections of gender gradients (male vs. female) and education gradients (low vs. high) for cancer (2015–2050)

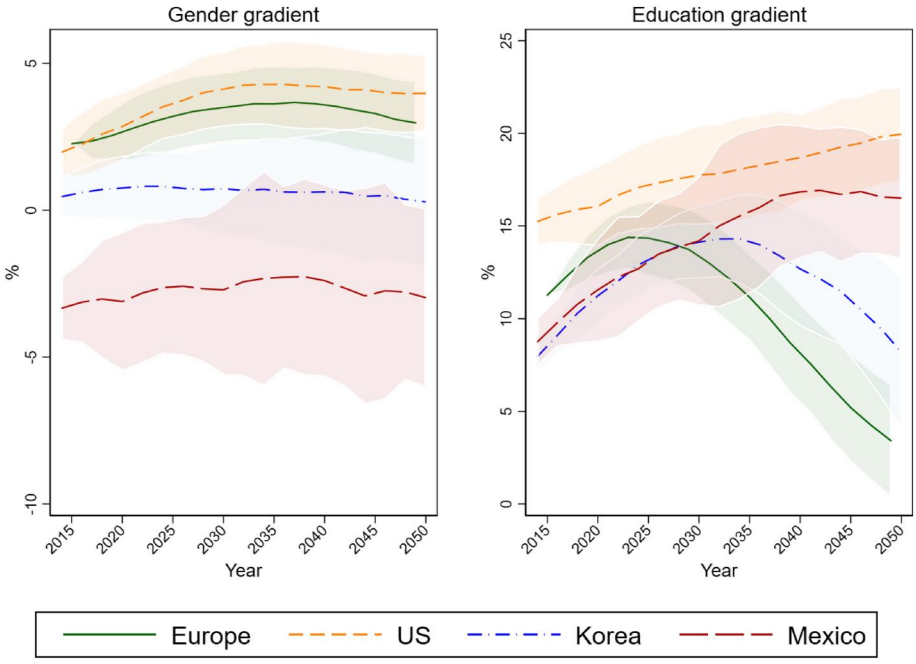

FIGURE 3 Projections of gender gradients (male vs. female) and education gradients (low vs. high) for diabetes (2015–2050)

In terms of disability rates, the aging process occurring in these countries will certainly have an effect in shaping ranking and trends. The highest value is recorded for South Korea (+14.1%), with United States and Europe following (+9.1% and +9%), while Mexico remains far below (+3.9%). In this case a possible explanation can be that despite the United States are not aging like Europe and South Korea, both their level and trends of obese people are far above the ones recorded in the other countries and, therefore, in absence of significant changes, this will increase the prevalence of disabled people.

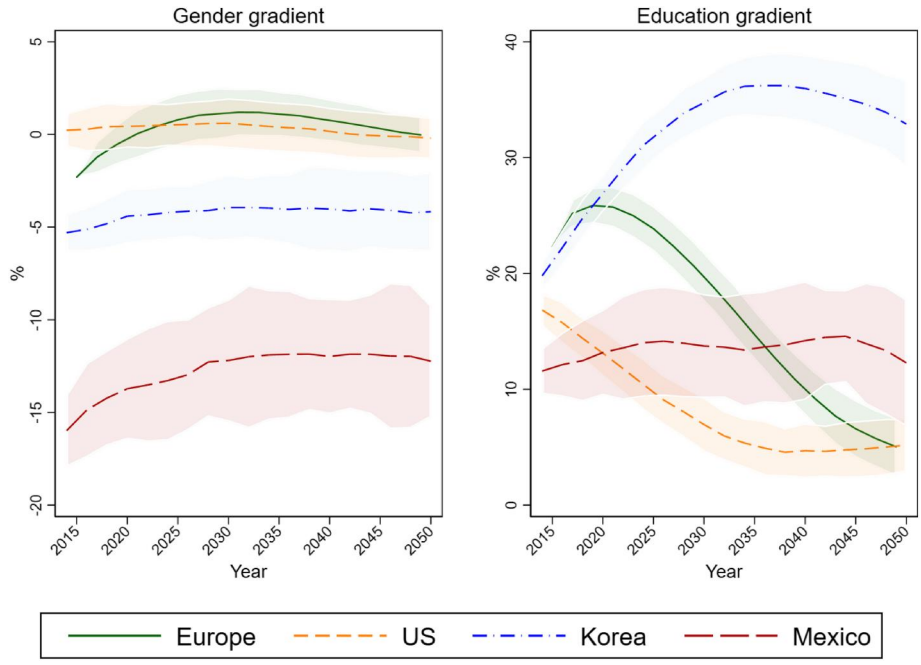

FIGURE 4 Projections of gender gradients (male vs. female) and education gradients (low vs. high) for hypertension (2015–2050)

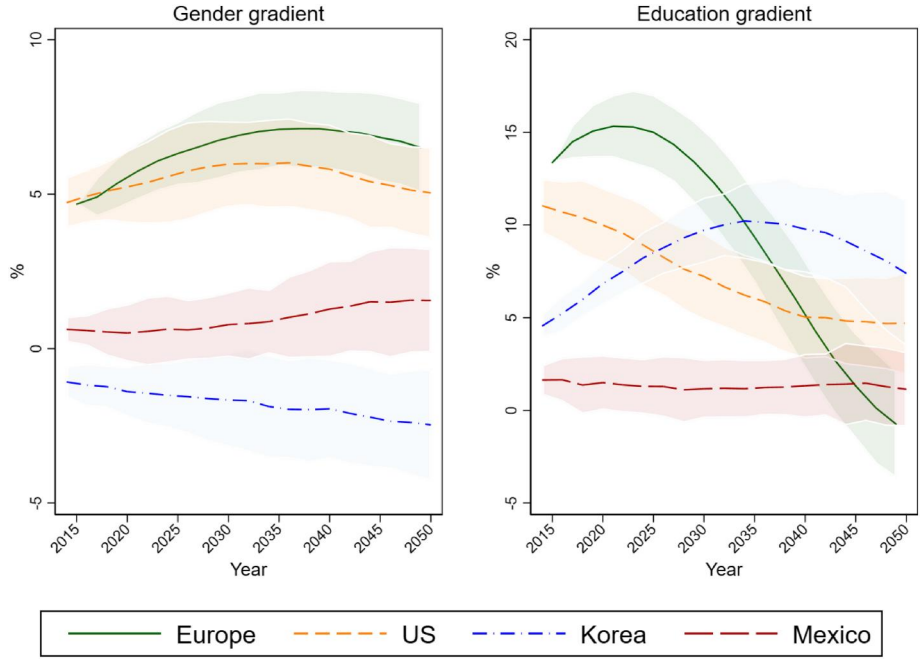

FIGURE 5 Projections of gender gradients (male vs. female) and education gradients (low vs. high) for heart disease (2015–2050)

5.2 | Prevalence of noncommunicable diseases

Noncommunicable diseases (NCDs) are chronic diseases that develop progressively over time, with increasing impacts on functional health and demand for health services. As such, they are responsible for most of the deaths around the world. The four main types of NCDs are cardiovascular diseases (like hypertension, heart diseases, and stroke), cancer, chronic respiratory diseases (such as COPD and asthma) and diabetes.[13] NCDs are driven by forces that include unhealthy lifestyles and population aging. Unhealthy diets and lack of physical activity may show up in people as increased blood pressure and blood glucose, elevated blood lipids, and obesity. These are called metabolic risk factors

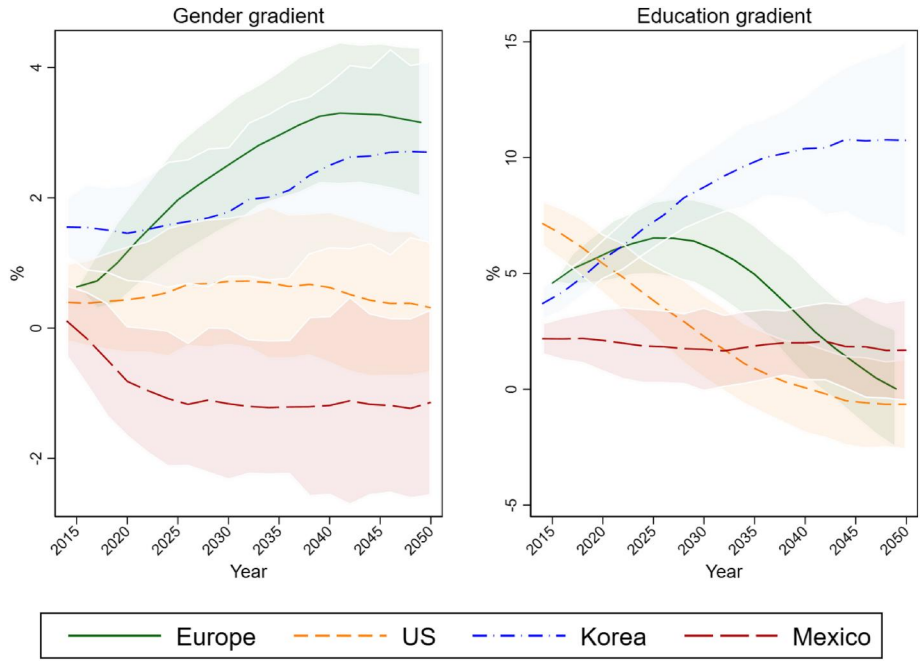

FIGURE 6 Projections of gender gradients (male vs. female) and education gradients (low vs. high) for stroke (2015–2050)

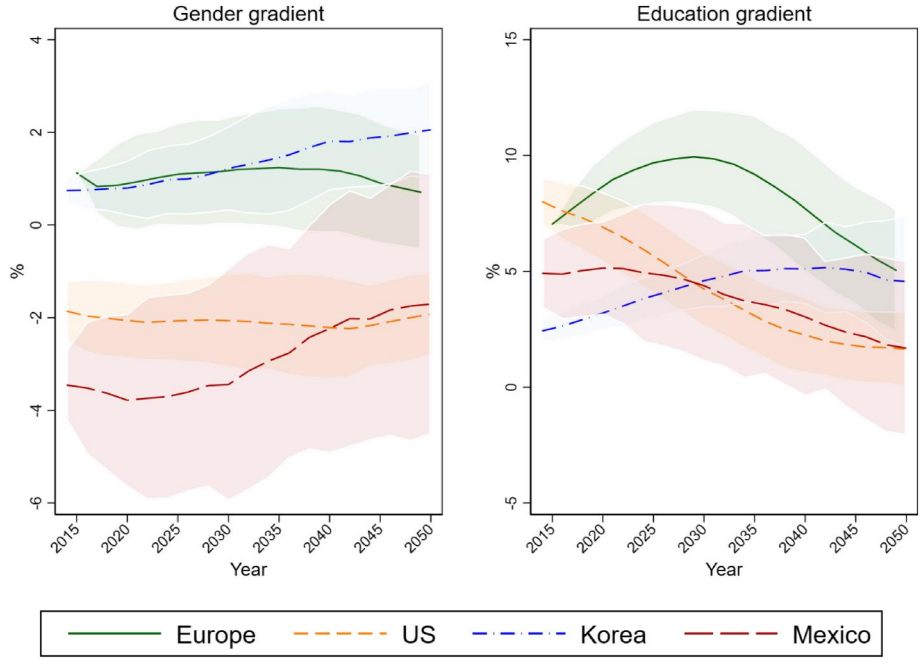

FIGURE 7 Projections of gender gradients (male vs. female) and education gradients (low vs. high) for lung disease (2015–2050)

that can lead to cardiovascular disease, the leading NCD in terms of premature deaths. NCDs affect people of all age groups, regions, and countries, although these conditions are often associated with the elderly population. For this reason it is important to have a clear understanding of the development patterns of these diseases, especially in those countries were population aging represents a major concern.

The most striking among our results is the heterogeneity in terms of prevalence trajectories that the different diseases show across countries. For example, as shown in Table 4, the nine European countries are projected to increase the prevalence of all NCDs analyzed more than any other country in this study, except for diabetes. It is particularly

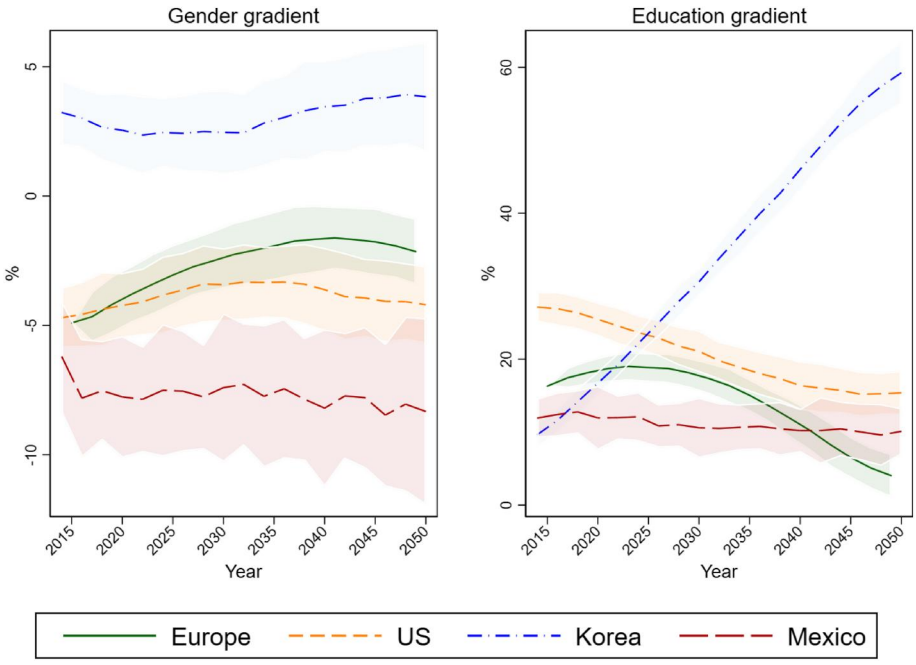

FIGURE 8 Projections of gender gradients (male vs. female) and education gradients (low vs. high) for being disabled (2015–2050)

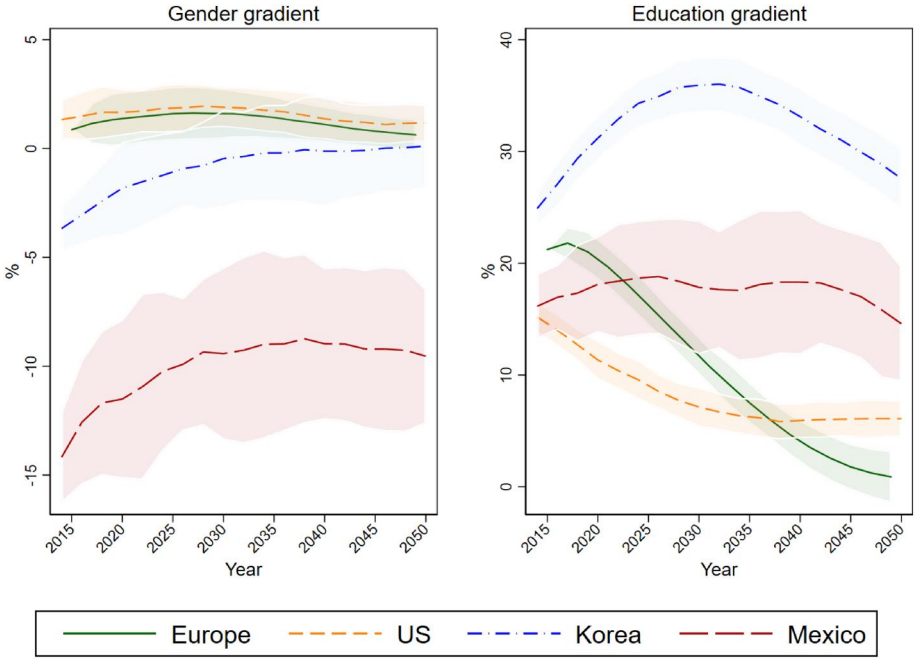

FIGURE 9 Projections of gender gradients (male vs. female) and education gradients (low vs. high) for having at least one chronic disease (2015–2050)

interesting to observe that, in 2050, the prevalences of heart disease, stroke, hypertension, diabetes, lung diseases, and cancer for these countries will be much closer to those in the United States than they were in 2014.

These trends could be partly explained with the faster aging process of the European population compared to the United States one, although this explanation could at a first sight be at odds with the NCDs trends forecasted in South Korea. In fact, although South Korea is the country in the world facing the fastest aging process (Kontis et al., 2017), Korean NCDs prevalences are not expected to growth as fast as the European ones.[14] The answer to

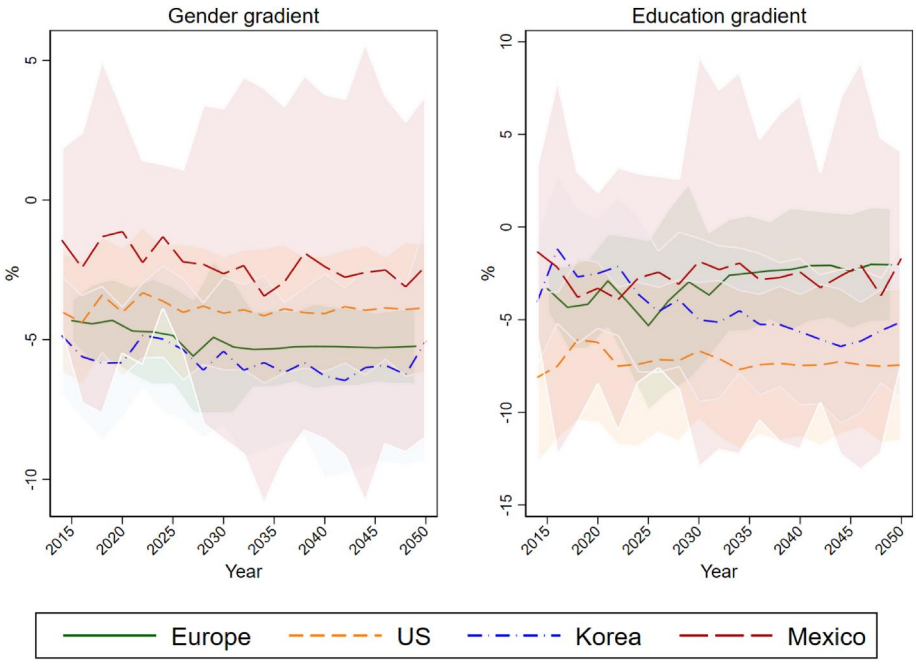

FIGURE 10 Projections of gender gradients (male vs. female) and education gradients (low vs. high) for life expectancy at 65 (2015–2050)

this apparent puzzle comes from observing that South Korea has distinct differential in terms of risk factors such as BMI (being among the fittest population in the world) and smoking rates (with an ever smoked population of about 30%).

The large increase in the projected disease prevalences in Europe compared to United States also depends on the significant differences in both chronic conditions' incidence and mortality. As far as the incidence is concerned, Table E.8 reports the transition models prediction of the incidence rates using a "minimal" specification, that is, controlling only for age and gender (and country dummies for SHARE) and the one, used for the final simulations presented here, which controls also for sociodemographics and risk factors. Consistently with Solé-Auró et al. (2015), we observe that Americans have higher incidence for heart disease and diabetes and lower incidence for hypertension and lung disease. Differently from Solé-Auró et al. (2015), we find no statistically significant differences in the incidence of both stroke and cancer. With the only exception represented by lung disease, all these differences are reduced when we move from a minimal to a full model specification but the difference between the predicted incidence rate in HRS vs SHARE remains statistically significant. Regarding mortality, we find that the European survival advantage does not vanish when we control for sociodemographics and risk factors.

Hypertension is by far the disease that is expected to grow more in terms of prevalence, while cancer and stroke show the lowest increase. Looking across countries, Mexico is the country where disease prevalences are projected to grow less. Another interesting evidence is represented by the forecast of lung disease prevalence, for which the European countries show a marked increase (+12.3%), with respect to South Korea (+3.2%) and United States (+2.8%). As already stated in Section 2, this could be partly explained by the different smoking rates in these countries. In fact, despite smoking rates have been declining over the last 20 years, in 2015 in Europe the percentage of current smokers was about 20%, much higher than in the United States (about 12%), South Korea (about 16%), and Mexico (about 8%). We also project an increase of 9.4% for cancer in Europe (from 10.5% to 19.9%) compared to a lower 3.2% in Mexico and 4.1% in South Korea.

In terms of the overall level of health, looking at the prevalence of individuals with at least one chronic disease, the picture that emerges shows that faster aging countries will face more problems. In particular, South Korea and Europe present the highest increase in prevalence for individuals with at least one chronic condition (+20.4% and +17.2%, respectively), while Mexico and United States limit the increase to 14.5% and 12.5%, respectively.

5.3 | Gender and educational gradients

One important feature of a microsimulation model is to allow for individual heterogeneity along several dimensions. In our case we focus on gender and educational gradients and how they are expected to evolve over time by disease and by country.[15] Figures 2–10 report these results with the corresponding confidence bands.

We observe no difference in the prevalence of cancer between males and females and across countries, whereas the projections show a significant increase in the prevalence of cancer among the more educated with respect to those with no high school diploma (Figure 2). Interestingly, while there are no differences in the projected dynamic between Europe, United States, and Mexico, we document an inverse U-shaped pattern for South Korea, with the education gradient increasing until 2030 and decreasing afterward. The left panel of Figure 3 shows that there is no gender gap in the future prevalences of diabetes in South Korea, on the other hand Europe and United States exhibit a positive and statistically significant gender gap although there are no differences between the two countries. Mexico is characterized by a significant difference in the prevalence between genders but the difference disappears after 2025. The education gradient is substantial and significant for all countries, with least educated individuals featuring a higher prevalence. We note that while the projections for Korea and Europe point toward an attenuation of this gap, United States and Mexico move in the opposite direction with the difference between the two groups of countries becoming significant towards the end of the simulation period.

As for hypertension, we find no gender gradient for United States and Europe, while females in Mexico and South Korea exhibit a higher prevalence. Over time, these gradients are projected to remain roughly constant. The education gradient is significant and expected to increase steeply in South Korea; this dynamic is different from the one projected for Europe, United States, and Mexico where the gradient should converge to lower values remaining significant (Figure 4). A similar convergence process, as reported in Figure 5, is expected to characterize the education gradient for hearth diseases, with all countries except Mexico starting from a positive and significant gradient that drops over time. With reference to the gender differences, the projections point toward a higher prevalence for women in South Korea whereas the opposite is expected to happen in both Europe and United States.

Figure 6 presents a positive, significant and increasing difference between men and women in Europe and South Korea, while the prevalence of stroke is expected to be the same across genders in United States and Mexico. The difference in prevalence between high and low educated individuals is projected to significantly increase in South Korea while the positive and significant gradient observed for Europe and United States should vanish in the long run.

As for lung disease, there is no difference between European men and women and the higher prevalence observed for Mexican women is expected to disappear after 2035. Both United States and Korea, with opposite signs, are characterized by a significant and persistent gender gap. Figure 7 also shows that a significant difference between low- and high-educated individuals is projected for Europe, United States, and Korea with the latter expected to increase over time.

As represented in Figure 8, South Korea is the only country where males have higher disability rates and this gap is expected to persist in the future. The difference between men and women is expected to decrease in Europe and remain constant and significant in United States and Mexico. Disability rates are highly correlated with educational attainment, with low-educated individual featuring higher prevalence in all countries. Nonetheless, Europe seems to be on a path pointing toward a reduction of this gap, United States and Mexico are expected to maintain it roughly constant while Korea is projected to increase the gradient. With reference to the prevalence of individuals with at least one chronic condition (Figure 9), United States and Europe are expected to reduce the significant education gradient whereas the difference is projected to remain constant in Mexico and South Korea, although with different patterns. With the exception of Mexico, the difference between men and women is expected to disappear by the end of the simulation horizon.

Finally, concerning LE at 65, as expected, the gender gradient is in favor of women, with a gap that seems to remain constant over time with no difference across countries. In terms of education, we observe that only United States and South Korea have a significant educational gradient, although no significant differences can be reported between countries (Figure 10).

6 | CONCLUDING REMARKS

The pace of population aging is much faster than in the past and all countries are already facing major challenges to ensure that their health and social systems are compatible with this demographic shift. In 2050, within OECD the share

of old people aged over 80 years will reach 10%. Unfortunately, this unprecedented trend will have important effects on prevalence rates of NCDs and of old-age disability, resulting on at least one third of the elderly population requiring some form of support in their daily lives (UN, 2011). Overall, as also pointed out by the WHO (WHO, 2017), this phenomenon will generate an excess demand for health care services that many health systems are currently not equipped to meet.

In this paper, we have conducted a joint effort to obtain a harmonized dynamic microsimulation model from combining different FEM-like models for Europe, South Korea, Mexico, and United States. Being a multirisk and multimorbidity state-transition dynamic microsimulation model accounting for the multidimensional nature of health status, the FEM represents a reliable tool to investigate the factors associated with the future evolution of NCDs.

Our results are very heterogeneous by country and over time and not always in favor of a specific group. For example, we found that while Europe and South Korea are characterized by a similar aging process, the dynamic of their NCDs prevalences is projected to be different due to a diverse distribution of risk factors in the population, differences in incidence and mortality rates. Our results show that Europe is "catching-up" with the United States while South Korea is not. Interestingly, we also observe that education plays an important role in shaping the evolution of the NCDs prevalence, in particular for diabetes, with Europe and South Korea that are predicted to close the education gradient while United States and Mexico that will be characterized by an increasing gap between high- and low-educated people. We believe that these results allow for a consistent comparison across countries and over time and, therefore, offer an important contribution in shedding light on the future needs of aging populations and in supporting policy makers to tackle the future societal challenges.

To investigate the determinants of the heterogeneous trajectories reported in this study is a topic for future research, for example, in a setting similar to the one presented in Michaud et al. (2011).

ACKNOWLEDGMENTS

Research reported in this publication was supported by the National Institute on Aging of the National Institutes of Health under award number P30AG024968, which funds the Roybal Center for Health Policy Simulation, part of the Leonard D. Schaeffer Center for Health Policy & Economics at the University of Southern California. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health or the Schaeffer Center. Tadeja Gracner acknowledges funding from the National Institutes of Health grant number R01HD087257.

CONFLICT OF INTEREST

Dr. Goldman reports grants from the National Institute on Aging during the conduct of the study. He also reports research support from Blue Cross Blue Shield of Arizona, Bristol Myers Squibb, Cedars-Sinai Health System, Edwards Lifesciences, Gates Ventures, Genentech, Gilead Sciences, Johnson & Johnson, Kaiser Family Foundation, Novartis, Pfizer, and Roche outside the submitted work. He reports personal fees from ACADIA Pharmaceuticals, Amgen, The Aspen Institute, Biogen, Celgene, GRAIL, and Precision Medicine Group outside the submitted work. Dr. Piano Mortari reports research support from Merck Sharp & Dohme outside the submitted work and personal fees from Farmafactoring Foundation and the Italian Ministry of Health outside the submitted work. Vincenzo Atella, Federico Belotti, Kim Daejung, Tadeja Gracner, and Bryan Tysinger have nothing to disclose.

DATA AVAILABILITY STATEMENT

The main data sources that support the findings of this study are the Health and Retirement Study, Survey of Health, Ageing and Retirement in Europe, Korean Longitudinal Study of Ageing and Mexican Health and Aging Study. Restrictions apply to the availability of these data, which were used under license for this study. The programs to obtain the harmonized versions of the aforementioned surveys are available at Gateway to Global Aging Data.

ORCID

Federico Belotti https://orcid.org/0000-0003-3169-0641
Dana Goldman https://orcid.org/0000-0001-8498-6396
Andrea Piano Mortari https://orcid.org/0000-0002-7220-2352
Bryan Tysinger https://orcid.org/0000-0002-8497-3664

ENDNOTES

[1] It is worth noting that in high income countries this phenomenon may have been exacerbated by the economic crisis started in 2007, which has limited public healthcare expenditure. In fact, between 2009 and 2012, public health expenditure in the Member States decreased by 0.6% each year, compared to the annual growth of 4.7% registered between 2000 and 2009, thus affecting the prevalence of a number of important diseases and risk factors (cardiovascular diseases, diabetes, mental distress, obesity, alcohol, and drug dependence) and partly changing the structure of mortality rates by cause (Atella et al., 2017; Karanikolos et al., 2013). Furthermore, according to the OECD (2014), the health spending reductions have exacerbated health inequalities.

[2] This is typical of models that try to obtain long-term expenditure projections when "the precise micro information on the individuals and their transition rates from one health status to another is missing or not reliable [...] Therefore, the models may not include all the relevant factors identified as affecting health care spending [...] and the results of the projections should not be interpreted as forecasts of expenditure." (EC, 2015, pp. 115–116).

[3] Some important studies based on FEM examine the consequences of delaying disease and disability (Goldman et al., 2013), the costs of obesity in older Americans (Lakdawalla et al., 2005), future disability trends (Chernew et al., 2005), fiscal consequences of worsening population health (Goldman et al., 2010; National Academies of Sciences, Engineering, and Medicine, 2015), the costs of cancer (Bhattacharya et al., 2005), the health and economic value of preventing disease after the age of 65 (Goldman et al., 2006), the value of cardiovascular risk reduction (Goldman et al., 2006, 2009), long-term health outcomes from medical innovation (Goldman et al., 2005; Lakdawalla et al., 2009), the health consequences of price controls (Lakdawalla et al., 2009), and the financial risk in Medicare spending from new medical technologies (Goldman et al., 2005).

[4] In what follows we use FEM when referring to the US FEM. The countries considered in the EU-FEM are Austria, Belgium, Denmark, France, Germany, Italy, Spain, Sweden, and Switzerland.

[5] A detailed methodological exposition of the FEM can be found in Appendix B of National Academies of Sciences, Engineering, and Medicine (2015) book.

[6] The 2-year time step is the result of the bi-annual structure of the HRS-like surveys, with the exception of the Mexican survey (see Section 4).

[7] This framework allows to take into account a great deal of heterogeneity and feedback effects. We make several restrictions on the transition risks permitted in the model. First, we allow a link between chronic conditions only if clinical research supports such a link. For instance, we allow hypertensive patients to have higher risk of heart disease, but we do not allow hypertensive patients to have higher risk on respiratory diseases such as chronic obstructive pulmonary disease (COPD).

[8] Transition models specification includes the log of Δ age as covariate to control for differences in the timing of interviews.

[9] For more information, please refer to www.g2aging.org.

[10] Details about SHARE can be found in Börsch-Supan et al. (2005) and Börsch-Supan and Jürges (2005). The SHARE survey collects data for a larger number of countries compared to those included in EU-FEM. We have excluded Greece, Poland, and Portugal because their sample size is too small to guarantee reliable estimates at the country level and the Netherlands because Wave 6 was not conducted for this country.

[11] The HS-SISSi database is provided by the Health Search Research Institute of the Italian Association of General Practitioners (SIMG). This database is a unique source of data including detailed information on prescribed drugs, laboratory tests, outpatient visits, and hospitalizations of more than 1.1 million unique Italian patients over the period 2000–2015, managed by 900 GPs over time. This pool of registers has produced a stock of information of about 25 million medical diagnosis, 100 million laboratory and diagnostic tests, 10 million blood pressure measurements, and 50 million drug prescriptions.

[12] In this context, other sources of uncertainty may stem from sampling variability of input sources and/or model specification.

[13] Other important NCDs include arthritis and other musculoskeletal conditions and depression which are not analyzed in this work.

[14] With low-birth rates, fewer marriages and longer lives, the trends combine to create a Korean population that is actually aging faster than any other developed country.

[15] The gradients are measured as difference between men and women and between low- and high-education levels. Therefore, positive values in gradients imply a higher exposition to chronic conditions for men and low-educated individuals.

REFERENCES

Astolfi, R., Lorenzoni, L., & Oderkirk, J. (2011). *A comparative analysis of health forecasting methods. Technical report*. Paris: OECD Publishing.

Astolfi, R., Lorenzoni, L., & Oderkirk, J. (2012). *Informing policy makers about future health spending: A comparative analysis of forecasting methods in OECD countries. Technical report, OECD*. Paris: OECD Publishing.

Atella, V., Belotti, F., Cricelli, C., Dankova, D., Kopinska, J., Palma, A., & Piano Mortari, A. (2017). The "double expansion of morbidity" hypothesis: Evidence from Italy. *CEIS Working Paper*, *15*.

Banks, J., Marmot, M., Oldfield, Z., & Smith, J. P. (2006). Disease and disadvantage in the United States and in England. *Journal of the American Medical Association*, *295*(17), 2037–2045.

Bardi, U., & Pierini, V. (2013). *Declining trends of healthy life years expectancy (HLYE) in Europe*.

Bhattacharya, J., Shang, B., Su, C. K., & Goldman, D. P. (2005). Technological advances in cancer and future spending by the elderly. *Health Affairs*, *24*, W5R53–W5R66.

Börsch-Supan, A., Brugiavini, A., Jürges, H., Mackenbach, J., Siegrist, J., & Weber, G. (2005). *Health, ageing and retirement in Europe: First results from the survey of health, ageing and retirement in Europe*. Mannheim: Mannheim Research Institute for the Economics of Aging (MEA).

Börsch-Supan, A., & Jürges, H. (2005). *The survey of health, ageing and retirement in Europe—Methodology*. Mannheim: Mannheim Research Institute for the Economics of Aging (MEA).

Case, A., & Deaton, A. (2015). Rising morbidity and mortality in midlife among white non-hispanic americans in the 21st century. *Proceedings of the National Academy of Sciences of the United States of America*, *112*(49), 15078–15083.

Case, A., & Deaton, A. (2017). Mortality and morbidity in the 21st century. In *Brookings papers on economic activity* (pp. 397–476). Springer.

Chen, B. K., Jalal, H., Hashimoto, H., chuan Suen, S., Eggleston, K., Hurley, M., Schoemaker, L., & Bhattacharya, J. (2016). Forecasting trends in disability in a super-aging society: Adapting the future elderly model to Japan. *The Journal of the Economics of Ageing*, *8*, 42–51.

Chernew, M. E., Goldman, D. P., Pan, F., & Shang, B. (2005). Disability and health care spending among medicare beneficiaries. *Health Affairs*, *24*, W5R42–W5R52.

Cutler, D., Lleras-Muney, A., & Vogl, T. (2008). Socioeconomic status and health: Dimensions and mechanisms. *NBER working papers 14333*. National Bureau of Economic Research, Inc.

Cutler, D. M., & Meara, E. (2004). Changes in the age distribution of mortality over the twentieth century. In *Perspectives on the economics of aging, NBER chapters* (pp. 333–366). National Bureau of Economic Research, Inc.

Donaldson, L., & Rutter, P. (2017). *Healthier, fairer, safer: The global health journey, 2007-2017*. World Health Organization.

European Commission (EC). (2015). *The 2015 ageing report*. European Commission, DG for Economic and Financial Affairs.

European Environment Agency (EEA). (2018). *Environmental indicator report 2018*. European Environment Agency.

Foreman, K. J., Marquez, N., Dolgert, A., Fukutaki, K., Fullman, N., McGaughey, M., Pletcher, M. A., Smith, A. E., Tang K., Yuan C.-W., Brown J. C., Friedman J., He J., Heuton K. R., Holmberg M., Patel D. J., Reidy P., Carter A., Cercy K., ... Murray C. J. L. (2018). Forecasting life expectancy, years of life lost, and all-cause and cause-specific mortality for 250 causes of death: Reference and alternative scenarios for 2016-40 for 195 countries and territories. *The Lancet*, *392*(10159), 2052–2090.

Goldman, D. P., Cutler, D., Rowe, J. W., Michaud, P.-C., Sullivan, J., Peneva, D., & Olshansky, S. J. (2013). Substantial health and economic returns from delayed aging may warrant a new focus for medical research. *Health Affairs*, *32*(10), 1698–1705.

Goldman, D. P., Cutler, D. M., Shang, B., & Joyce, G. F. (2006). The value of elderly disease prevention *Forum for Health Economics & Policy*, 9(2), 1.

Goldman, D. P., Michaud, P.-C., Lakdawalla, D., Zheng, Y., Gailey, A., & Vaynman, I. (2010). The fiscal consequences of trends in population health. *National Tax Journal*, *63*(2), 307–330.

Goldman, D. P., Shang, B., Bhattacharya, J., Garber, A. M., Hurd, M., Joyce, G. F., Lakdawalla, D. N., Panis, C., & Shekelle, P. G. (2005). Consequences of health trends and medical innovation for the future elderly. *Health Affairs*, *24*, W5R5–W5R17.

Goldman, D. P., Zheng, Y., Girosi, F., Michaud, P.-C., Olshansky, S. J., Cutler, D., & Rowe, J. W. (2009). The benefits of risk factor prevention in Americans aged 51 years and older. *American Journal of Public Health*, *99*(11), 2096–2101.

Gonzalez-Gonzalez, C., Tysinger, B., Goldman, D. P., & Wong, R. (2017). Projecting diabetes prevalence among Mexicans aged 50 years and older: The future elderly model-Mexico (FEM-Mexico). *BMJ Open*, *7*(10), e017330.

Grossman, M. (2006). Education and nonmarket outcomes. In *Handbook of the economics of education* (pp. 577–633). Elsevier.

Guzman-Castillo, M., Ahmadi-Abhari, S., Bandosz, P., Capewell, S., Steptoe, A., Singh-Manoux, A., Kivimaki, M., Shipley, M. J., Brunner, E. J., & O'Flaherty, M. (2017). Forecasted trends in disability and life expectancy in England and wales up to 2025: A modelling study. *The Lancet Public Health*, *2*(7), e307–e313.

Karanikolos, M., Mladovsky, P., Cylus, J., Thomson, S., Basu, S., Stuckler, D., Mackenbach, J. P., & McKee, M. (2013). Financial crisis, austerity, and health in Europe. *The Lancet*, *381*(9874), 1323–1331.

Kasajima, M., Hashimoto, H., Suen, S., Chen B., Jalal H., Eggleston K., & Bhattacharya J. (2020). Future projection of the health and functional status of older people in Japan: A multistate transition microsimulation model with repeated cross-sectional data. *Health Economics*.1–22. https://doi.org/10.1002/hec.3986.

Kim, D., Chen, C., Tysinger, B., Park S., Chong M. Z., Wang L., Zhao M., Yuan J.-M., Koh W.-P., Yoong J., Bhattacharya J., & Eggleston K. (2019). Smoking, life expectancy, and chronic disease in South Korea, Singapore, and the United States: A microsimulation model. *Health Economics*.1–13. https://doi.org/10.1002/hec.3978

Klenk, J., Keil, U., Jaensch, A., Christiansen, M. C., & Nagel, G. (2016). Changes in life expectancy 1950-2010: Contributions from age- and disease-specific mortality in selected countries. *Population Health Metrics*, *14*(1), 20.

Kontis, V., Bennett, J. E., Mathers, C. D., Li, G., Foreman, K., & Ezzati, M. (2017). Future life expectancy in 35 industrialised countries: Projections with a Bayesian model ensemble. *The Lancet*, *389*(10076), 13231335.

Lakdawalla, D. N., Goldman, D. P., Michaud, P.-C., Sood, N., Lempert, R., Cong, Z., de Vries, H., & Gutierrez, I. (2009). US pharmaceutical policy in a global marketplace. *Health Affairs*, *28*(1), 138–150.

Lakdawalla, D. N., Goldman, D. P., & Shang, B. (2005). The health and cost consequences of obesity among the future elderly. *Health Affairs*, *24*, W5R30–W5R41.

Li, J., & O'Donoghue, C. (2013). A survey of dynamic microsimulation models: Uses, model structure and methodology. *International Journal of Microsimulation*, *6*(2), 3–55.

Luy, M. (2003). Causes of male excess mortality: Insights from cloistered populations. *Population and Development Review*, *29*(4), 647–676.

Mathers, C. D., Stevens, G. A., Boerma, T., White, R. A., & Tobias, M. I. (2015). Causes of international increases in older age life expectancy. *The Lancet*, *385*(9967), 540–548.

Mattson, M. P., Allison, D. B., Fontana, L., Harvie, M., Longo, V. D., Malaisse, W. J., Mosley, M., Notterpek, L., Ravussin, E., Scheer, F. A. J. L., Seyfried, T. N., Varady, K. A., & Panda, S. (2014). Meal frequency and timing in health and disease. *Proceedings of the National Academy of Sciences of the United States of America*, *111*(47), 16647–16653.

Meara, E. R., Richards, S., & Cutler, D. M. (2008). The gap gets bigger: Changes in mortality and life expectancy by education, 1981–2000. *Health Affairs*, *27*(2), 350–360.

Michaud, P.-C., Goldman, D., Lakdawalla, D., Gailey, A., & Zheng, Y. (2011). Differences in health between Americans and western Europeans: Effects on longevity and public finance. *Social Science & Medicine*, *73*(2), 254–263.

National Academies of Sciences, Engineering, and Medicine. (2015). *The growing gap in life expectancy by income: Implications for federal programs and policy responses*. The National Academies Press.

OECD. (2014). *Health at a glance: Europe 2014*. OECD Publishing.

OECD. (2016a). *The economic consequences of outdoor air pollution*. OECD Publishing.

OECD. (2016b). *Society at a glance 2016: OECD social indicators*. OECD Publishing.

OECD. (2017). *Preventing ageing unequally*. Organisation for Economic Co-operation and Development.

OECD. (2019). *Society at a glance 2019: OECD social indicators*. OECD Publishing.

Oksuzyan, A., Juel, K., Vaupel, J., & Christensen K. (2000). Men: Good health and high mortality. Sex differences in health and aging. *Aging Clinical and Experimental Research*, *20*(2), 91–102.

Ronkainen, J., Nedelec, R., Juola, T., & Sebert, S., & LongITools Study Group. (2021). *LongITools: Dynamic longitudinal exposome trajectories in cardiovascular and metabolic non-communicable diseases*. Forthcoming in Environmental Epidemiology.

Roodman, D. (2011). Fitting fully observed recursive mixed-process models with cmp. *Stata Journal*, *11*(2), 159–206.

Solé-Auró, A., Michaud, P.-C., Hurd, M., & Crimmins, E. (2015). Disease incidence and mortality among older Americans and Europeans. *Demography*, *52*(2), 593–611.

United Nations (UN). (2011). *General Assembly Prevention and control of non-communicable diseases. Report of the Secretary-General, Sixty-sixth session*. New York: United Nations.

United Nations (UN). (2015a). *World population prospects: The 2015 revision, methodology of the united nations population estimates and projections. Technical report*. Department of Economic and Social Affairs, Population Division.

United Nations (UN). (2015b). *World population prospects: The 2015 revision, volume i: Comprehensive tables. Technical report*. Department of Economic and Social Affairs, Population Division.

United Nations (UN). (2015c). *World population prospects: The 2015 revision, volume ii: Demographic profiles. Technical report*. Department of Economic and Social Affairs, Population Division.

Van Oyen, H., Nusselder, W., Jagger, C., Kolip, P., Cambois, E., & Robine, J.-M. (2013). Gender differences in healthy life years within the EU: An exploration of the "health-survival" paradox. *International Journal of Public Health*, *58*(1), 143–155.

World Health Organization (WHO). (2014). *Ambient air pollution: A global assessment of exposure and burden of disease*. World Health Organization.

World Health Organization (WHO). (2017). *Noncommunicable diseases progress monitoring. Are we meeting the time-bound United Nations targets?*. World Health Organization.

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

How to cite this article: Atella V, Belotti F, Kim D, et al. The future of the elderly population health status: Filling a knowledge gap. *Health Economics*. 2021;1–19. https://doi.org/10.1002/hec.4258