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The Future of the Elderly Population Health Status: Filling a Knowledge Gap

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Abstract

The ageing process in OECD countries calls for a better understanding of the future disease prevalence, life expectancy 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 (FEM) family for thirteen OECD countries, with the aim of reproducing for the first time comparable long-term trends in individual health status across OECD. The FEM is a multi-risk multi-morbidity dynamic microsimulation model to project health status and health demand. Given the dynamic structure of the model, we allow individual health status to evolve over time according to individual characteristics. Our model provides forecasts of the evolution of life expectancy and prevalences of major chronic conditions and disabilities, overall, by gender and by education. We find a catch-up of the considered European countries main chronic conditions prevalence with the US and a relevant and persistent educational gradient in the health status of elderly patients. Our findings represent a valid contribution to support policy makers in designing and implementing effective interventions in the healthcare sector.

Keywords: Population ageing, Disease burden, Microsimulation, Health care demand, Education gradient, OECD.

JEL: I1, J1, J11, J14.

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1 Introduction

The impact of ageing 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 grey" 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 ageing process in several OECD countries (Cutler and 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 (particularly with the decrease in infant mortality), extending LE at birth and diminishing the LE gap between males and females (Atella et al., 2017; Klenk et al., 2016; Mathers et al., 2015; OECD, 2016). In particular, medical technologies are among the main determinants for the increase in LE: they have turned many, once deadly, diseases into chronic conditions.

The macroeconomic consequences of these trends are relevant as they pose challenges for countries' economies. For those countries where fewer workers are available and labor force participation rates drop, economic output is projected to fall. Some estimates suggest that until 2060 OECD countries are likely to see modest - though not catastrophic - declines in the rate of economic growth (Bloom et al., 2011, 2015). Furthermore, population ageing gives rise to concerns regarding the health of older populations. Older people have greater health and long-term care needs than younger people, leading to increased expenditure. They are also less likely to work if they are unhealthy, and could impose an economic burden on families and society. Overall, older people need support, but the burden of providing this support will be more and more on the shoulders of a smaller portion of the population. These effects, combined with the weak economic growth, result in increasingly stringent public finances posing serious threats to the financial sustainability of the social security and healthcare systems (Harper, 2014).

Further, these problems will be exacerbated by income and health inequalities that have been increasing from one generation to the next. As reported by OECD (OECD, 2017), these inequalities are higher among people starting now their working life than among today's elderly. This implies that the future elderly will present a more heterogeneous situation: they will all live longer but some of them will be unemployed multiple times in their working lives and will earn lower wages, while others will have enjoyed higher, stable earning paths. This will result in accumulation of inequalities in education, employment and wealth over the life-course, which in turn may end up in large inequalities in health status. Those health systems that in the past have not managed the myriad health problems and long-term care needs of older people, and have not sufficiently emphasised disease prevention, can heterogeneously respond to the new challenges posed by the current and future demographic reality and by the associated changes in population health.

Based on this evidence, longer LE can be seen as a potentially "good" or "bad" news, depending on the quality of the "extra" life years lived. In particular, at aggregate level, an older and unhealthy population implies an extra burden in terms of both pensions and health care expenditure. In this respect, there exists a sound epidemiological literature arguing that some of the life years gained over the last decades are being spent in poor health (Olshansky et al., 1991; van Gool et al., 2011). According to Kassebaum et al. (2016), despite global health improvement and life expectancy increases, people spend more time with reduced functional health status. This implies that in the recent decades the absolute expansion of morbidity has occurred.[1] These results are particularly true for high income countries during the 1990-2015 period, when trends in years of functional health loss have increased more than expected and similar trends are forecasted for the near future. According to Guzman-Castillo et al. (2017), forecasts made for the UK show that from 2015 to 2025 a quarter of the extra years gained after the age of 65 will involve disability.[2]

More importantly, according to Bardi and Pierini (2013) and Van Oyen et al. (2013), since 2003 many European countries have witnessed a significant decline in healthy life expectancy 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 more importantly, across gender: women tend to live longer, but spend more years in bad health with respect to men.[3] Similarly, recent work in US 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 indicate the substantial heterogeneity in health, even in high-income countries.

Given this evidence and ongoing trends, an accurate forecast of the future health status of the population could thus offer 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 modelling 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 (UN, 2015a,b,c), models allowing forecasting population long-term

[1]It is important to highlight that the expansion of morbidity can be interpreted in both absolute and relative terms. Absolute expansion implies that as people live longer lives, they loose more years due to functional health loss, whereas relative expansion implies that as people live longer lives, the ratio of years of functional health lost to life expectancy increase. Based on Kassebaum et al. (2016) results, it must be noted that despite the "absolute" expansion, we also observe a relative compression of morbidity.

[2]This study offers an improvement with respect to previous studies such as the (Kassebaum et al., 2016) due to the adoption of a Markov model with interacting states rather than a simple static model.

[3]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 the 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 (cardio-vascular diseases, diabetes, mental distress, obesity, alcohol and drug dependence) and partly changing the structure of mortality rates by cause (Karanikolos et al., 2013; Atella et al., 2017). Furthermore, according to the OECD (2014), the health spending reductions have exacerbated health inequalities.

health status at individual level are rare, such as those in the US (Goldman et al., 2013) and UK (Guzman-Castillo et al., 2017). More recently, Foreman et al. (2018) has developed a model based on aggregated data from the Global Burden of Disease (GDB) 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 1990-2016, to generate predictions for 2017-40 in 195 countries and territories. Concerning Europe, the only tool available to policy makers 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.[4] 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 harmonisation and sophisticated and complex modelling methods that take into account the evolution of health, economic and demographic variables at individual and cohort levels. Microsimulation models (MSMs) have emerged as a useful tool to answer these questions (Astolfi et al., 2011, 2012). Among this class of models, Future Elderly Model (FEM) (Goldman et al., 2005), using the Health and Retirement Study (HRS) data, has been extensively used to explore a variety of policy questions over the last decade in the US, and modified versions of FEM have been employed in other countries (for a recent application, see National Academies of Sciences, Engineering, and Medicine (2015) or Chen et al. (2016)).[5]

In this study we present novel results obtained from combining different FEM-like models for Europe (EU-FEM), Korea, Mexico and US. The FEM is a multi-risk and multi-morbidity state-transition dynamic microsimulation model for projecting the health status of the population, aggregated from projecting individual lives.[6] 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 socio-economic outcomes). The wide set of robustness checks conducted in US, which account for both internal and external model validation, show that FEM provides a reliable representation of the future

[4]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. 115-6).

[5]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), 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 (Lakdawalla et al., 2009; Goldman et al., 2005), 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).

[6]A detailed methodological exposition of the FEM can be found in Goldman et al. (2015) and Atella et al. (2018) for the EU-FEM. The countries represented in the EU-FEM are Austria, Belgium, Denmark, France, Germany, Italy, the Netherlands, Spain, Sweden and Switzerland.

disease burden for a large share of the population aged 50 and older. As such, this study offers an important contribution in shedding light on future needs of ageing 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 presents the data employed to build the scenarios and to obtain the simulations, while Section 5 presents the results. Finally, Section 6 concludes.

2 Health conditions in OECD

According to the OECD (2019), life expectancy 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 healthcare. 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 life expectancy 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 and will continue to rise, due to population ageing: 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.

Figure 1 presents the changes in the number of deaths and the number of years lived with disabilities (YLDs) in OECD between 1990 and 2017. Overall, the number of deaths decreased significantly for every age group up to age 50, remained constant up to age 80 and increased for people aged 80+. The largest gains were for infants and for early childhood. The increase in the number of deaths for individuals aged 80+ is a mere representation of the fact that on average the age of death has been postponed and occurs with a relatively higher frequency in that age group. In terms of YLDs the picture that emerges is rather different. We observe a small decrease for individuals in the age classes up to 35 years and an increase for all others. What is remarkable is the increase in the age group from 40 to 80 years in YLDs when the mortality rate has remained constant.

In terms of mortality rates, the reductions in the recent decades have been undoubtedly driven by technological progress, both in terms of processes and products, as well as enhanced healthcare organisation. In terms of YLDs, on the one hand, the increases result from the elderly translating their technology driven LE gains into years lived with chronic conditions and disabilities, and on the other hand, the 40+ individuals experiencing an earlier onset of chronic conditions and disabilities (Van Oyen et al., 2013; Case and Deaton, 2017; Atella et al., 2017). This last pattern is likely to be driven by different factors such as heterogeneous changes in socio-economic conditions by age groups, lifestyle changes, less healthy environment and better and anticipated diagnostic activity by physicians.

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, Hungary and Turkey, and lowest in Mexico. Among adolescents, 12% smoke weekly. Alcohol consumption in the OECD averaged 9 litres 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. One out of four European 15-year-olds reports to have been drunk at least twice in their life. 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 Korea and Norway, albeit from low levels. Self-reported obesity has gone up among 15-year-olds from 11% in 2001-02 to 17% in 2013-14 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 WHO estimates that overall, 92% of the world's population is breathing air above the PM2.5 guidelines (Donaldson and 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 to 9 million premature deaths by 2060, and cost 1% of global GDP (OECD, 2016). Also, todays populations are increasingly exposed at 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). Finally, there seems to be consensus on the correlation between mental and physical health, and between these latter and risk factors such as poor nutrition, low education, unemployment and alcohol consumption. For instance, depression is often present in individuals with physical diseases, affecting 33% of individuals with cancer, 29% with hypertension and 27% with diabetes (OECD, 2019). In most economically advanced countries such pathologies account for 70-80% of healthcare expenditures and the affected individuals are those who benefit the most from the healthcare systems (The Economist Intelligence Unit, 2012).

These changes in the patterns of LE and YLDs suggest that the interactions between ageing, risk factors, technology and churning conditions are becoming increasingly complex and estimating future health and demographic projections using standard aggregated econometric models and forecasting tools is not anymore possible, unless we accept large forecasting errors. The heterogeneity in healthy ageing as a function of gender, socio-economic status and age class experienced today is substantial, and being able to account for various trajectories of chronic diseases is particularly important from a policy perspective. If similar trends were confirmed in the coming decades, there would be relevant implications for the healthcare systems, which should face an older society characterised, at the same time, by increasing morbidity of chronic diseases and per-capita medical expenses.

3 Model description

As mentioned in Section 2, the health status trends witnessed over the last four decades across the OECD countries are compatible with the hypothesis of an absolute expansion of morbidity, where a non-marginal share of the years of life gained are years spent with chronic conditions and disabilities. Moreover, the increase in life expectancy is mostly determined by technological advances aimed at reducing mortality rather than the prevalence of chronic conditions and disabilities. In order to understand the underlying dynamics and to design useful policy interventions, we employ the FEM, originally developed to examine health and health care costs among the elderly Medicare population in the US (Goldman et al., 2005), which we extend to Korea, Mexico and 9 European countries.

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 (National Academies of Sciences, Engineering, and Medicine, 2015). 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 and O'Donoghue, 2013). Further, this heterogeneity allows for the implementation of detailed interventions altering the way in which people access healthcare 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 policy outcomes module and *iv*) the replenishing cohort module. A schematic overview of the model is provided in Figure 2. The model starts at time T with an initial population of 50+ individuals, which transits at time $T+2$ thanks to the transition module.[7] 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 3 for a summary of the transitioned outcomes by types).[8] At time $T+2$ the replenishing cohort module replenishes the 50- and 51-years-old individuals in order to maintain the 50+ population structure at each simulation step. Finally, the policy module summarizes individual-level outcomes to produce the outcomes of interest, such as disease prevalence and life expectancy.

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, labour 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

[7]The two-years 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).

[8]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 COPD.

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 and will refer the interested readers to more details in the technical documentation cited below. All models are fed by harmonised data developed by the Gateway to Global Aging Data project, whose main aim is to harmonise variable definitions with the RAND HRS data, thus greatly simplifying the adaptation of the FEM to other countries and later to simplify the comparison in terms of results.[9] The Health and Retirement Study, as well as all other HRS family surveys used in this work (SHARE, MHAS and KLOSA) allows to explore topics related to work, retirement, work quality, health, health care, psychological factors, aspects of daily life and socio-economic positions among people aged 50 or over. The surveys were collected using computer-assisted personal interviews (CAPI) supplemented by self-completed paper-and-pencil questionnaires.

Concerning the SHARE dataset, 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 EUR-FEM. The current version of EUR-FEM is based on an unbalanced panel sample of 101,176 observations (47,629 individuals included in at least two of the five SHARE waves).[10] In order to generate future replenishing cohorts that reflect temporal trends, 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 Korean Longitudinal Study of Aging (KLoSA), a longitudinal study of individuals over age 45 in the Republic of Korea (South Korea). We used the Harmonised KLoSA dataset which contains Waves 1, 2, 3, and 4 as of October 2015 (National Academies of Sciences, Engineering, and Medicine, 2015). The KLoSA data are used to compute the health transition models that comprise the core of the K-FEM, 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 once again represent the population aged 50 and older. As for the other datasets, the MHAS content includes health in multiple domains,

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

[10] Details about SHARE are described in Börsch-Supan et al. (2005) and Börsch-Supan and Jürges (2005). The countries included in EUR-FEM are Austria, Belgium, Denmark, France, Germany, Italy, Spain, Sweden and Switzerland. SHARE data are available for a larger number of countries, but we have excluded Greece, Poland and Portugal because their sample size is too low 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 hospitalisations of more than 1,1 millions 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 millions medical diagnosis, 100 millions laboratory and diagnostic tests, 10 millions blood pressure measurements and 50 millions drug prescriptions.

health behaviours and risk factors, socioeconomic conditions, work history, health insurance, health expenditures and family background, among others. The Mexican FEM differ from the HRS data in one important methodological aspect, the inter-wave periods. As mentioned above, the FEM was created to be used with the US HRS, a longitudinal survey collected every 2 years; MHAS has a 2-year gap between the first (2001) and second (2003) wave and a 9-year gap between the second and third (2012) wave. To overcome this methodological difference, we use the MHAS 2001 and 2003 waves to estimate health transitions and 2-year incidence, and we use the 2012 wave as the baseline to start the microsimulation. In other words, we imposed the 2001-2003 health transitions onto the 2012 MHAS population (Gonzalez-Gonzalez et al., 2017).[12]

For the US, the HRS dataset is the main data source for the model. These data have been supplemented with merged Social Security covered earnings histories and data on health trends and health care costs coming from 3 major health surveys in the U.S. (National Academies of Sciences, Engineering, and Medicine, 2015).

Country-specific summary statistics for socio-economic and health variables, both for initial stock (2014 for US, Mexico and Korea; 2015 for Europe) and new cohorts (2016 for US, Mexico and Korea; 2017 for Europe) are shown in Tables 1 and 2, respectively. All the stock populations are characterised by a larger women's share and by an average age higher than 65. Korea has the least educated elderly population, followed by the US and Mexico. With reference to chronic conditions the US is characterized by the highest prevalence of any of the conditions modelled except for diabetes, that is more frequent in Mexico. As for risk factors, the US exhibits the highest share of severely obese, followed by Mexico, while Korea displays the highest prevalence of non obese people. Disabled elderly are more prevalent in the US, both in terms of Activities of Daily Living (ADL) and Instrumental Activities of Daily Living (iADL). Similar patterns are observed for the incoming cohorts (Table 2).

5 Projections through 2050

In this section we present the simulation results at 2050 for a large set of health indicators such as life expectancy at 65 years (LE) and prevalence rates for cancers, diabetes, heart diseases, hypertension, lung diseases, stroke, presence of at least 1 chronic condition and disability (defined as any ADL, iADL, or living in a nursing home). Results are presented for Korea, Mexico, US and for the pooled 9 European countries. Furthermore, to help filling the knowledge gap in terms of future health status of the elderly, we provide information disaggregated by gender and education to understand the levels and trends of such gradients. All results have been obtained under the assumption that the outcome drivers follow past trends and no intervention is planned in the future. Furthermore, given the common model structure and data collection and harmonisation 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.

In Table 4 we present the population aggregated results for three points in time (2014, 2030 and 2050) and as absolute difference between 2050 and 2014. In Figures 3

[12] The accuracy of this approach has been tested by applying the 2001 prevalence and the 2001/2003 incidence to project the prevalence of diabetes in 2012. The estimated prevalence and the prevalence observed in MHAS 20123 have been compared and the estimates were quite similar, leading to conclude that this approach is reasonable. These results are available in the technical online supplementary appendix in (Gonzalez-Gonzalez et al., 2017).

and 4 we show the simulated gender and education gap by country and disease. Thanks to these evidence we can easily summarise and compare both levels and trends across countries which allows to highlight the relevant differences.

5.1 Life expectancy at age 65 and disability

As we can see from Table 4, although we overestimate the average LE at 65 for the European countries, the models are able to replicate the ranking in levels across these countries, with Korea and Europe representing the best performing country/area and Mexico the less performing one. Korea and Mexico are the countries that are predicted to have the highest increase in LE at 65 until 2050 (+3,92 and + 4,15 years respectively), while US should be the less performing country (+0,77 years). These values seems 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).

In terms of disability rates, the ageing process occurring in these countries will certainly have an effect in shaping the ranking and the trends. The highest value is recorded for Korea (11.97%), with Europe and US following (+8.21% and +8.30%), while Mexico remains far below (+4.09%). In this case a possible explanation can be that despite the US are not ageing like Europe and Korea, their level of obese people is far above the one recorded in the other countries and, therefore, in absence of significant changes, this will increase the prevalence of disabled people.

5.2 Prevalence of non communicable diseases (NCDs)

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 causes of death around the world. The four main types of noncommunicable diseases are cardiovascular diseases (like hypertension, heart diseases and stroke), cancer, chronic respiratory diseases (such as chronic obstructed pulmonary disease and asthma) and diabetes.[13] NCDs are driven by forces that include rapid unplanned urbanization, globalization of unhealthy lifestyles and population ageing. Unhealthy diets and a 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 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 older age groups. For this reason it is important to have a clear understanding of the patterns of development of these diseases, especially in those countries were population ageing represents a major concern.

The most striking results is the heterogeneity in terms of prevalence trajectories that the different diseases have across countries and years. For example, as shown in Table 4, the 9 European countries in our sample are on average projected to increase the prevalence of all NCDs analysed more than any other country in this study. It is particularly striking to observe that, in 2050, the prevalence for heart disease, stroke, hypertension, diabetes, lung diseases and cancer, for our European countries will be

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

much closer to those of the US than they were in 2014. These trends could be easily explained with the faster ageing process of the European population compared to the US one, although this explanation could at a first sight be at odds with the NCDs trends forecasted in Korea. In fact, although Korea is the country in the world facing the fastest ageing process (Kontis et al., 2017), Korean NCDs prevalence will most likely not reach US' prevalence.[14] The answer to this apparent puzzle come from observing that 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%). This is a result that has never been presented before and could represent an extremely important evidence for policy makers around the world to take into account when designing future health care policies, in light of the difficult situation they are already facing in terms of public health care system economic sustainability.

Hypertension is by far the disease that is expected to grow more in terms of prevalence, while cancer show the lowest increase. Looking across countries Mexico seems to be the country where disease prevalences will grow less. Another interesting evidence is represented by the forecast of lung disease prevalence, for which the European countries show a marked increase (+12.1%), with respect to Korea (+2.93%) and US (+1.94%). 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 smoker was about 20%, much higher than in the US (about 12%), Korea (about 16%) and Mexico (about 8%). We also forecast an increase of +8.36% for cancer in Europe (from 10.47% to 18.83%) compared to a lower 2.78% in Mexico (from 2.81% to 5.59%) and +3.39% in Korea.

In terms of overall level of health, looking at the prevalence of individuals with at least one chronic disease, the picture that emerges shows that ageing countries will face more problems. In particular, Europe and Korea present the highest increase in prevalence for individuals with at least one chronic disease (+18.39% and +18.12%, respectively), while Mexico and US limit the increase to about half (+10,99% and +9.25%, respectively).

5.3 The role of 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 will evolve over time by disease and by country.[15] In Figure 3 and 4 we present the same results reported in Table 4 by gender and education. In order to summarise the info, and for sake of clarity, in both figures each graph reports the forecasts of the gender and educational gaps by country in percentage points. This means that, for example, in Figure 3, in the case of diabetes, the gender gap is positive (males are more exposed than females) in three out of four countries and increases over time in some countries, which implies that in the future males should be exposed more than female to diabetes. Similarly, in Figure 4, for diabetes, the educational gradient is positive in all countries and increases in some countries, which

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

[15] Gradients are measured as difference between “male" and “female" for gender and difference between “low" and “high" education levels for education. Therefore, positive values in gradients imply a higher exposition for men and low educated individuals.

implies that low educated individuals should be more exposed than high educated one in the future.

With respect to gender, the results are very heterogeneous by country and over time and not always in favour of a specific group. Concerning LE, as expected, the gender gradient is in favour of women, with a gap that seems to remain constant over time, although very heterogeneous across countries: in Korea it reaches 6 years, while Mexico it remains in a range of 2-3 years. With the only exception of Korea, women present a higher prevalence of disability, with Mexico recording the highest gap (-7.5%). For cardiovascular diseases (heart disease, stroke and hypertension) the highest gradients are recorded for the 9 European countries and for US (with the exception of stroke, where the gradient is almost zero). Korea presents a negative gap with a decreasing trend for heart diseases, a positive gap and an increasing trend for stroke and a negative gap and constant trend for hypertension. Mexico presents a positive gap with an increasing trend for heart diseases, a negative gap and a decreasing trend for stroke and a negative gap and increasing trend for hypertension. For cancer the gap shows a penalty for women, although the effect seems to reduce over time. This penalty can be partly explained as a survival effect: women and to live longer than men. For diabetes, the gradient penalises men in all countries but Mexico. In particular, Europe and US are the places where men seem to suffer more and the gradient is increasing. Finally, in terms of lung disease Europe and Korea show a positive and constant gap against men and a negative and constant gap for Mexico and US.

In terms of education, the results are more homogeneous across diseases and, consistent with the literature, we observe a gradient in favour of high educated individuals. Concerning LE at 65, the minimum gap is recorded for Europe and Mexico (in a range of 2-4 years), while for US we observe the largest gap (in a range of 7-8 years). More interestingly, these gaps show a dynamic that is heterogeneous across countries, with Korea that presents an increasing gap (from 4 to about 6 years), Europe with a decreasing gap (from 4 to about 2 years), and US that remain almost constant around 7 years. For NCDs, the only exception is represented by cancer, where the negative gradient seems to favour low educated individual. However, this puzzles can be easily explained as a survival effect: more educated individuals just survive longer, creating a selection effect that biases the gradient. Coherently with the selection effect, the gradient decreases over time. Korea represents the only exception to this interpretation, with a positive gradient that seems to favour high educated people. For the other diseases the trajectories are heterogeneous across countries and no clear pattern emerges. Korea is the country where the educational gradient seems to the largest both in levels and in changes: in 2050 Korea presents the largest gradient for heart diseases, stroke, hypertension, prevalence of individuals with at least one disease and prevalence of disables. The lowest gradients are recorded for Europe for all diseases but Cancer.

6 Conclusions

The pace of population ageing 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 an harmonised dynamic micro-simulation model from combining different FEM like models for Europe, Korea, Mexico and US. Being a multi-risk and multi-morbidity 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. For example, we found that while Europe and Korea are characterised by a similar ageing process the dynamic of their NCDs prevalences is projected to be different due to a diverse distribution of risk factors in the population. Our results show that Europe is "catching-up" with the US while 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 Korea that are predicted to close the education gradient while US and Mexico will be characterised 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, they offer an important contribution in shedding light on future needs of ageing populations and in supporting policy makers to tackle the future societal challenges.

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Figure 1: Changes in number of deaths and years lived with disabilities in OECD countries by age class (1990-2017).

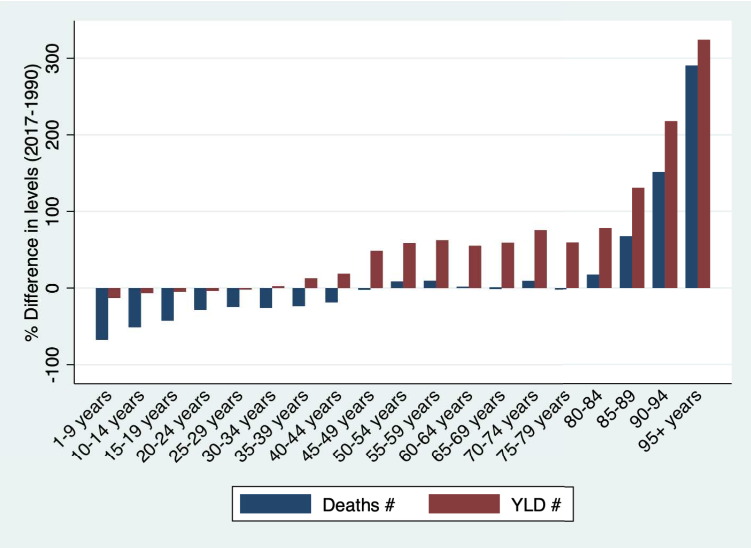

Figure 2: The "FEM-like" model flow

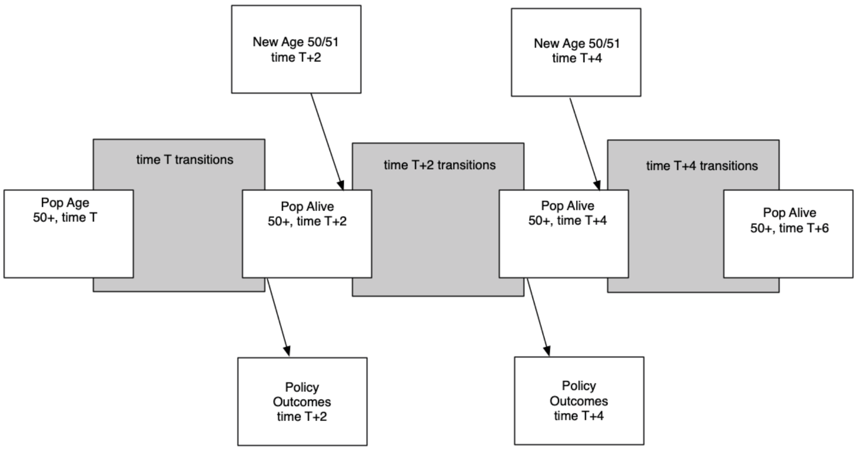

Figure 3: Simulations of gender gradients (Male *vs.* Female) by disease and country (2015-2050).

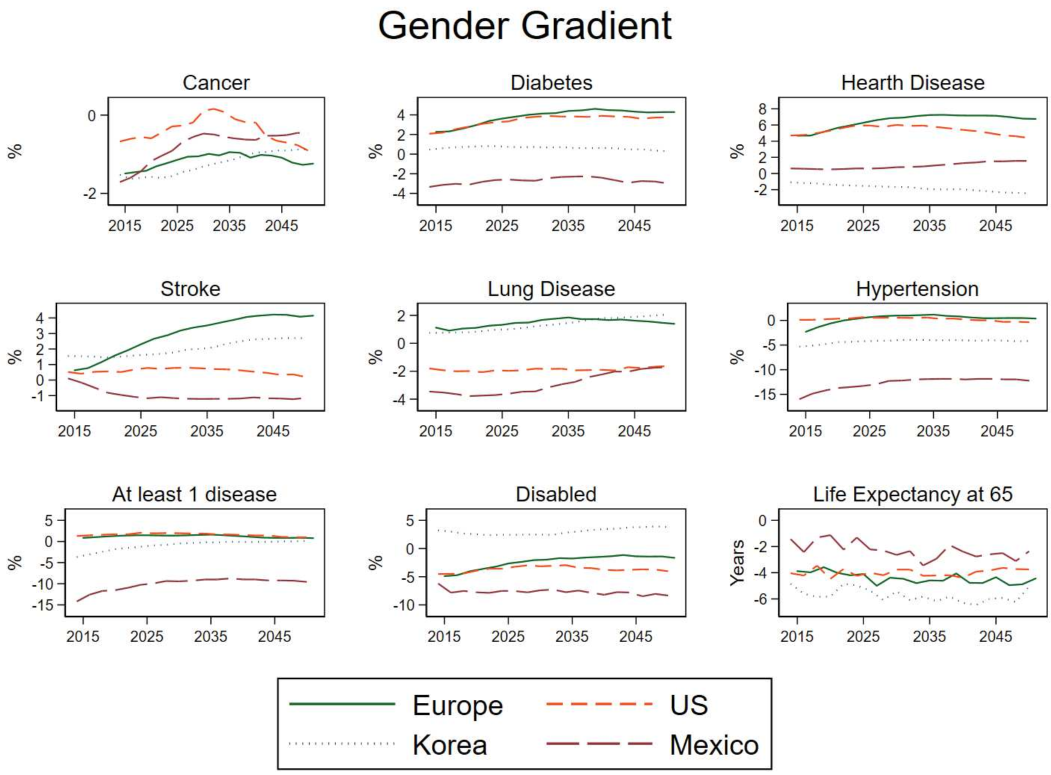

Figure 4: Simulations of education gradients (Low *vs.* High) by disease and country (2015-2050).

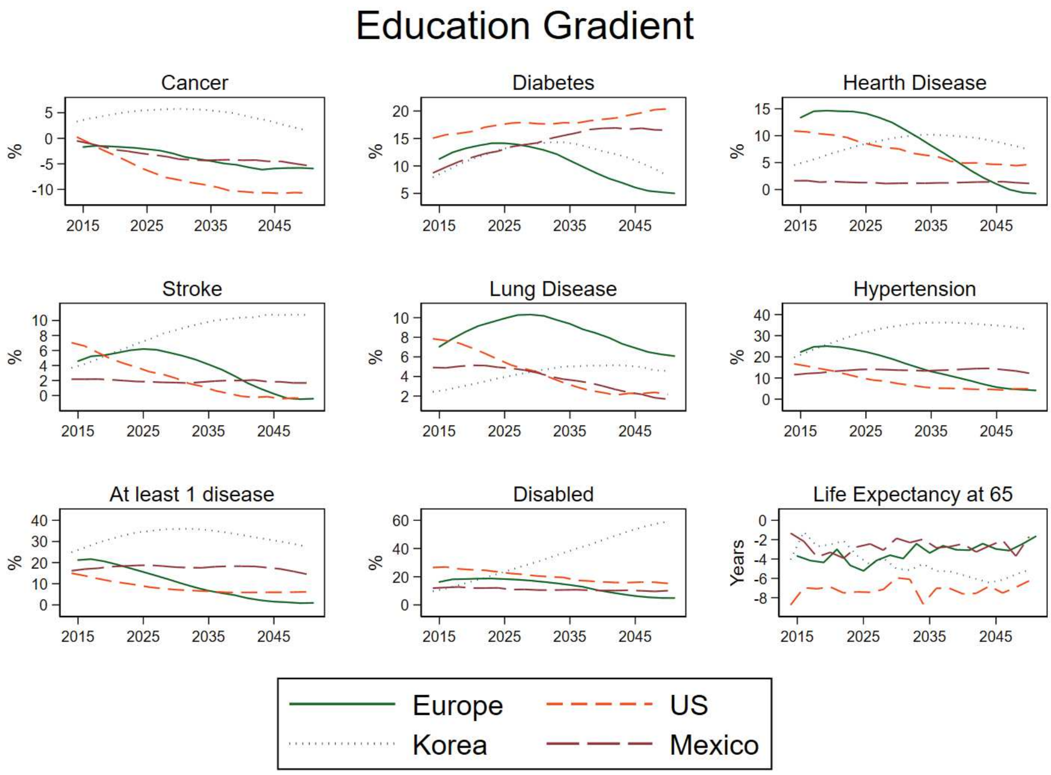

Table 1: Starting Population

	Europe		US		Mexico		Korea	
Variable	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Male	0.45	0.498	0.445	0.497	0.433	0.495	0.429	0.495
Age	67.991	10.753	68.201	12.461	65.432	9.9	66.735	10.179
Less than high school	0.194	0.395	0.213	0.409	0.871	0.335	0.622	0.485
Some college and above	0.272	0.445	0.446	0.497	0.099	0.298	0.108	0.311
Hypertension	0.387	0.487	0.59	0.492	0.432	0.495	0.391	0.488
Diabetes	0.116	0.32	0.231	0.422	0.238	0.426	0.165	0.371
Cancer	0.071	0.258	0.161	0.367	0.031	0.175	0.049	0.216
Lung disease	0.076	0.265	0.114	0.318	0.092	0.288	0.031	0.174
Heart disease	0.165	0.371	0.262	0.44	0.044	0.206	0.081	0.273
Stroke	0.048	0.213	0.104	0.305	0.035	0.184	0.054	0.226
Ever smoked	0.505	0.5	0.587	0.492	0.11	0.313	0.307	0.461
Current smoking	0.178	0.383	0.154	0.361	0.234	0.423	0.16	0.367
BMI $<$ 25	0.422	0.494	0.32	0.466	0.351	0.477	0.764	0.425
BMI $\geq$ 25 BMI $<$ 30	0.406	0.491	0.358	0.48	0.42	0.494	0.223	0.416
BMI $\geq$ 30	0.171	0.377	0.322	0.467	0.229	0.42	0.013	0.115
No Limitations (ADLs)	0.902	0.298	0.771	0.42	0.849	0.358	0.952	0.214
1 ADL	0.052	0.223	0.089	0.285	0.077	0.267	0.015	0.12
2 or more ADLs	0.046	0.209	0.14	0.347	0.074	0.262	0.034	0.18
No Limitations (IADLs)	0.955	0.207	0.855	0.352	0.898	0.302	0.891	0.312
1 IADL	0.026	0.158	0.076	0.266	0.059	0.236	0.052	0.221
2 or more IADLs	0.019	0.138	0.068	0.252	0.042	0.201	0.058	0.233
Obs	32857		20666		14627		7457	

Table 2: Replenishing Cohorts

	Europe		US		Mexico		Korea	
Variable	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Male	0.416	0.493	0.47	0.499	0.352	0.478	0.398	0.49
Age	51.194	0.47	51.905	3.868	50.637	0.481	51.502	0.501
Less than high school	0.076	0.265	0.138	0.345	0.831	0.375	0.23	0.421
Some college and above	0.328	0.469	0.539	0.499	0.121	0.327	0.244	0.43
Hypertension	0.234	0.423	0.437	0.496	0.206	0.405	0.146	0.354
Diabetes	0.05	0.218	0.16	0.366	0.058	0.233	0.057	0.232
Cancer	0.035	0.183	0.059	0.236	0.023	0.15	0.039	0.193
Lung disease	0.026	0.159	0.052	0.222	0.049	0.216	0.004	0.064
Heart disease	0.055	0.228	0.108	0.311	0.017	0.13	0.022	0.148
Stroke	0.018	0.133	0.028	0.165	0.009	0.093	0.01	0.1
Ever smoked	0.457	0.498	0.547	0.498	0.159	0.365	0.301	0.459
Current smoking	0.212	0.409	0.236	0.425	0.167	0.373	0.205	0.404
No Limitations (ADLs)	0.958	0.201	0.868	0.339	0.932	0.251	0.998	0.045
1 ADL	0.023	0.15	0.066	0.248	0.048	0.213	-	-
2 or more ADLs*	0.019	0.136	0.066	0.249	0.02	0.141	0.002	0.045
No Limitations (IADLs)	0.987	0.115	0.915	0.28	0.963	0.19	0.972	0.166
1 IADL	0.004	0.059	0.073	0.26	0.033	0.179	0.024	0.154
2 or more IADLs	0.01	0.099	0.012	0.111	0.004	0.066	0.004	0.064
Obs	4794		1930		694		492	

*For Korea, the ADL are categorized as "No Limitations" and "3 or more ADLs".

Table 3: 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 exp. 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 1 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

Table 4: FEM projections

Diseases	Countries	Years			Δ
		2014*	2030*	2050*	2050-2014*
Cancer	Europe	10,47	16,11	18,83	8,36
	Korea	5,31	7,66	8,70	3,39
	Mexico	2,81	4,21	5,59	2,78
	US	14,78	19,32	20,46	5,68
Diabetes	Europe	15,48	23,22	28,84	13,36
	Korea	15,50	19,04	23,72	8,22
	Mexico	20,35	20,41	21,38	1,03
	US	22,53	30,62	35,77	13,24
Heart Diseases	Europe	17,35	27,78	33,64	16,29
	Korea	7,58	11,58	15,87	8,30
	Mexico	3,53	4,13	4,96	1,43
	US	23,36	30,21	32,38	9,02
Hypertension	Europe	48,54	63,79	69,94	21,40
	Korea	36,38	44,46	51,50	15,12
	Mexico	36,71	42,45	46,26	9,55
	US	58,04	66,38	69,52	11,47
Lung Diseases	Europe	10,37	18,56	22,50	12,13
	Korea	2,82	4,06	5,75	2,93
	Mexico	9,54	15,81	16,96	7,42
	US	10,14	12,35	12,08	1,94
Stroke	Europe	6,50	12,10	15,56	9,06
	Korea	5,15	7,86	11,47	6,32
	Mexico	3,18	3,74	4,03	0,85
	US	8,21	11,26	13,49	5,28
At least 1 disease	Europe	63,56	77,59	81,95	18,39
	Korea	49,59	60,00	67,71	18,12
	Mexico	51,56	59,35	62,56	10,99
	US	73,66	81,60	82,91	9,25
Disabled	Europe	14,34	17,96	22,55	8,21
	Korea	11,89	16,29	23,87	11,97
	Mexico	16,36	18,18	20,45	4,09
	US	23,79	27,50	32,09	8,30
Life Expectancy at 65	Europe	21,29	21,59	23,16	1,86
	Korea	22,90	25,08	26,81	3,92
	Mexico	15,73	17,51	19,88	4,15
	US	19,07	18,81	19,84	0,77

*For the 9 European countries the years are 2015, 2031, 2051 and 2015-2051, respectively.

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