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FORECASTING TRENDS IN DISABILITY IN A SUPER-AGING SOCIETY: ADAPTING THE FUTURE ELDERLY MODEL TO JAPAN

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Forecasting Trends in Disability in a Super-Aging Society: Adapting the Future Elderly Model to Japan
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ABSTRACT

Japan has experienced pronounced population aging, and now has the highest proportion of elderly adults in the world. Yet few projections of Japan's future demography go beyond estimating population by age and sex to forecast the complex evolution of the health and functioning of the future elderly. This study adapts to the Japanese population the Future Elderly Model (FEM), a demographic and economic state-transition microsimulation model that projects the health conditions and functional status of Japan's elderly population in order to estimate disability, health, and need for long term care. Our FEM simulation suggests that by 2040, over 27 percent of Japan's elderly will exhibit 3 or more limitations in IADLs and social functioning; almost one in 4 will experience difficulties with 3 or more ADLs; and approximately one in 5 will suffer limitations in cognitive or intellectual functioning. Since the majority of the increase in disability arises from the aging of the Japanese population, prevention efforts that reduce age-specific disability (or future compression of morbidity among middle-aged Japanese) may have only a limited impact on reducing the overall prevalence of disability among Japanese elderly.

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1. Introduction

Population aging is a global phenomenon, with significant implications for individuals and policymakers alike. Yet across the globe, there are wide differences both in the rate of aging and the current age structure in society (Kapteyn 2010). For many years, researchers have attempted to shed light on the potential implications of global population aging, but for some countries in the world, the impact of a rapidly aging society can no longer be considered a hypothetical scenario far off in the future (Schoeni and Ofstedal 2010), Japan, in particular, has experienced pronounced population aging, with over 26.3% of the population aged 65 and over[1], and now has the highest proportion of elderly adults in the world[2]. Yet few projections of Japan's future elderly health needs go beyond estimating population by age and sex to forecast the complex evolution of the health and functioning of the future elderly. In the last two decades, methodological advances in population studies and simulations have made it possible to estimate the needs of the future elderly, with implications for potential policy response (Schoeni and Ofstedal 2010). The goal of this study is to develop a model that projects the health conditions, disability and functional status of Japan's elderly population. Such a model can support evidence-based assessments of future demand for health care, long-term care, public pensions, welfare and other government-supported programs, as well as labor force participation.

Japan's super-aging demographic trends present a series of policy challenges for which a detailed model of competing risks for the future elderly would be useful (Ogawa, Mason et al. 2007). Long-term care insurance program spending (Miyazawa, Moudoukoutas et al. 2000) and medical care spending (Dow, Philipson et al. 1999, Lee and Skinner 1999, Gerdtham, Lundin et al. 2005, Bech, Christiansen et al. 2011) will be most directly impacted. The flattening of the pyramidal age structure and aging in general have implications for optimal retirement decisions (Poterba 2014), savings behavior (Bloom, Canning et al. 2003, Finkelstein and Poterba 2004), the progress of interest rates (Philipson and Becker 1998, Prettner and Canning 2012), family

[1] http://www.stat.go.jp/english/data/jinsui/tsuki/index.htm
[2] http://www.soumu.go.jp/johotsusintokei/whitepaper/ja/h25/html/nc123110.html. Japan overtook Italy and Germany to have the highest proportion of elderly adults by 2008.

caregiving (Gannon and Davin 2010) and labor participation (Imrohoroğlu and Kitao 2012), as well as intergenerational wealth transfer programs and policies (Behrman and Parker 2013). Other studies have investigated the relative merits of a pay-as-you-go versus a funded pension system in light of population aging (Schieber 2010, Venti 2010), or the impact of aging on disability and qualify of life (Oshio, Shimizutani et al. 2010, Suzman 2010, Singh 2013). But many facets of social and economic life are also implicated beyond pension and retirement policies (Manton, Stallard et al. 1998, Aísa, Pueyo et al. 2012), including issues as seemingly far-removed as fertility (Grant, Hoorens et al. 2004, Cullinan, Gannon et al. 2013), immigration (Martínez and Marín 2014), and national security (Coleman and Rowthorn 2011).

Population aging is also linked to the broader macroeconomic challenges confronting Japan (Hoshi and Ito 2014). Japan's net debt-to-GDP ratio in 2012 was approximately 134% (compared to 87% for the US and 82% for the UK). Japan's fiscal situation is not sustainable, partly because as an aging society, Japan's household savings rate will likely decline, as will the working-age population, further slowing the growth of private sector financial assets (the predominant holders of Japan's government bonds (Hoshi and Ito 2014)). Japan's fiscal situation appears not to be sustainable, due primarily to the combined effects of GDP stagnation and rising social security expenditures resulting from its aging population. Since 2008, the Japanese government has called for a broad range of reforms on pension, health care, and other social security programs, with primary budget balance as the goal. Yet Japan's population aging will certainly make this goal a difficult one to achieve. More generally, population aging has implications for economic growth beyond the raw support ratio, including possible impacts on the rate of entrepreneurship, innovation, and productivity growth (Lee 2014).

Our work sheds light on the challenges that Japan faces by projecting the needs of its future elderly. Most population projections for Japan have not modeled health status and disability, but simply projected population by age and sex. A few recent studies have attempted to go further (Fukawa 2007, Ogawa, Retherford et al. 2010, Shimizutani, Fujii et al. 2014). For example, Shimizutani et al. (2014) recently used the

JSTAR data to estimate factors, including health, that affect the retirement decisions of the middle-aged and elderly in Japan. They develop a simulation model for enrollment into Japan's disability program. While these studies represent an encouraging trend, there is much to gain from a more flexible and powerful simulation model of population aging in a country of Japan's global economic importance. Surveys such as the Health and Retirement Study and the Wisconsin Longitudinal Study have increasingly combined traditional surveys with biometric measurements, and included measures of psychological and cognitive ability using adaptive testing techniques (Hauser and Weir 2010). Advances have also occurred in the use of demographic mortality models that take into account the biological processes of aging and exposure to environmental factors such as smoking and obesity (Yashin, Akushevich et al. 2013). Such models that simulate cohort evolution based on mortality selection given the underlying prevalence and incidence of comorbidities may improve the predictive powers of future elderly projections, and lend themselves to manipulations of parameters to simulate alternative scenarios and outcomes (Zheng 2014).

This paper extends the literature by developing a demographic and economic state-transition micro-simulation model for Japan that enables analysis of the impact of demographic change, aging, and population health on disability and care receiving. We estimate the model using the recently released multiple waves of the Japan Study of Aging and Retirement (JSTAR) survey, the Japanese version of the family of internationally comparable surveys that include the U.S. Health and Retirement Study (HRS), the English Longitudinal Survey on Ageing (ELSA), and the Survey on Health, Aging and Retirement in Europe (SHARE). We choose a Japan-specific dataset in order to reflect Japan's specific morbidity and mortality burden, which may differ from that of the United States due to genetic, dietary, healthcare, lifestyle and other behavioral and environmental differences between Japan and the United States (See, e.g., Keys, Menotti et al. 1984). To do so, we first estimate disease transition probabilities for diseases prevalent among Japanese middle-aged and elderly populations. We then use the JSTAR and national age-sex-specific mortality data to develop appropriate estimates of conditional mortality for the relevant diseases among the Japanese elderly. Third, we construct a state-transition model based on the original FEM. Finally, we estimate how the constellation of medical conditions for each age-sex group affect functional status of Japan's future elderly population as measured by Activities of Daily Living (ADLs), Instrumental Activities of Daily Living (IADLs), and additional measures of cognition and social functioning.

We find that by 2040, over 27 percent of Japan's elderly will exhibit 3 or more limitations in IADLs and social functioning; almost one in 4 will experience difficulties with 3 or more ADLs; and approximately one in 5 will suffer limitations in cognitive or intellectual functioning. The majority of the increase in disability arises from the aging of the Japanese population. Therefore, the economic impact of prevention efforts that reduce the underlying comorbid conditions associated with disability may be limited. The remainder of this paper is organized as follows. Section 2 describes Japan's demographic and institutional background. Section 3 describes the data and the methodology for adapting the FEM to Japan. Section 4 presents the empirical results regarding disability of Japan's future elderly. The final section discusses policy implications. A technical appendix describes in greater detail the operationalization of the future elderly model in the Japanese context.

2. Background

The Japanese populace is well educated, with a nearly 100 percent literacy rate, mandatory nine-year education, and 34.7% of the population ultimately attaining a college education.[3] The size of Japan's working population in 2010 was 59.4% of the total population—roughly 65 million workers, which is similar to the rate in the United States (Index Mundi 2011). However, as a result of longevity increase and fertility decline, Japan is experiencing dramatic population aging. Like most high-income countries, Japan has nearly zero population growth, with a total fertility rate well below replacement. More than 26.3 of Japan's population is 65 or older[4], and this proportion is projected to grow dramatically over the next few decades.

[3] http://www.e-stat.go.jp/SG1/estat/ListE.do?bid=000001053739&cycode=0
[4] http://www.stat.go.jp/english/data/jinsui/tsuki/index.htm

Since 1960, Japan has achieved the highest gains in life expectancy at age 65 among all OECD countries, with an increase of almost ten years for women and over seven years for men (OECD 2013). Life expectancies at age 65 and at age 80 (11.4 for women, 8.4 for men) are the highest in the world except for France (OECD 2013). Nearly 40% of the population will be aged over 65 years by 2050, and the proportion of the population aged over 80 is expected to nearly triple between 2010 and 2050 (rising from 6% to 16% (OECD 2013)).

Alongside mortality declines, Japan has experienced changes in morbidity, suggesting the need for models such as the FEM to predict the future health of the elderly. The rate of obesity in Japan (4%) is lower than nearly all other high-income countries—with obesity in the US almost ten-fold the low rates of Japan. While hypertension prevalence remains high in Japan, rates have been declining since the 1980s. Japan has among the lowest death rates from ischemic heart disease (IHD) in the OECD (OECD 2013). By contrast, cancer incidence and mortality have increased, likely due to Japan's aging population. [5] Cancer is the leading cause of death in Japan (similar to Canada, Denmark, France, and the Netherlands). While rates of stomach cancer are higher than in the West and the incidence of once-rare colorectal cancer is increasing, lung cancer has emerged as the main cause of death among patients with cancer (OECD 2013). Given the smoking rates among men, cancer mortality rates among men are not surprisingly more than twice those for women.

The confluence of low fertility, longevity, and reduced morbidity and mortality from many diseases (except for cancer) has resulted in a decline in Japan's population for over 7 years. Projections predict that the population will shrink to 87 million by 2060, with nearly 40 percent over the age of 65. In light of these demographic trends, Japan represents a "super-aging society" even among aging OECD countries.[6] In the US, the

[5] Crude mortality is increasing in Japan, while age-adjusted mortality has been relatively constant or decreasing since the late1990s, suggesting that population aging is the main driver of increased number of cancer deaths. http://ganjoho.jp/data/professional/statistics/backnumber/2013/fig14.pdf

[6] According to estimates in "Live Longer, Work Longer" Keese, M. (2006). Live longer, work longer, OECD., between 2000 and 2050 the ratio of older nonworking individuals per worker will increase from approximately 38% to 70% in the OECD, almost doubling.

Old Age Dependency Ratio (OADR, ratio of population age 65 and above to age 20 to 64) is projected to rise from 22% in 2010 to 39% in 2050 (Lee 2014). In Japan, the OADR was already 39% in 2012 and is projected to reach more than 70% by 2050 (OECD 2007).

While the sharp rise in the old age dependency ratio has been offset somewhat by the high labor force participation among the Japanese elderly compared to many other OECD countries, it remains questionable whether Japan can escape from a huge burden of social security and health expenditure (Ichimura, Shimizutani et al. 2009). For example, the poverty rate—defined as the proportion of individuals with equalized disposable income less than 50% of the median income—is higher in Japan (21.1%), and disproportionately among the elderly[7], compared to most European countries (Ichimura, Shimizutani et al. 2009).

The rapid aging of the Japanese population poses a significant challenge to the government to maintain the financial viability of its health and long-term care system. Among all OECD countries, Japan allocates the greatest share of hospital expenditure to people aged 65 and over (64%), associated with the fact that it also has the highest share of people in that age group (23%; (OECD 2013)). Only in Israel and Japan (among OECD countries) has health spending growth as a percent of GDP accelerated rather than declined since the financial crisis of 2009 (OECD 2013), and both a stagnant GDP and population aging are important reasons.

The changing mortality and morbidity pattern in Japan increasingly strains Japan's health and long-term care systems in ways that contrast with many other OECD countries. For example, Japan and Korea have the longest hospital stays, at more than double the OECD average of 8.0 days in 2011. A salient reason is that many acute care hospitals provide a significant share of long-term care services ("social admissions") and serve the functions of skilled nursing facilities in a country like the United States. For example, Japan has the highest expenditure per discharge for cancer among OECD countries, probably because of its much longer lengths of stay (OECD 2013). Japan

[7] http://www.gender.go.jp/kaigi/senmon/kansieikyo/siryo/ka39-2-3-1.pdf

also has, by far, the highest number of MRI and CT scanners per capita. Largely because of a 2010 change in OECD accounting rules that now includes long-term care expenditures in total health expenditures, Japan's ratio of health spending to GDP now exceeds the OECD average, revealing the true extent of Japan's total financial burden from its aging population.

To inform future policy decisions such as the sustainability of health spending and the long-term care insurance program, Japan's policymakers need a tool to forecast the health and functioning of the future elderly. This paper takes an initial step toward that goal.

3. Data

Our data derives from the Japanese Study of Aging and Retirement (JSTAR), one of Japan's first longitudinal datasets on middle-aged and elderly Japanese specifically designed for cross-national scientific investigation of aging and retirement. Two waves of interviews in 2007 and 2009 surveyed 3,862 respondents between 47 and 77 in five Japanese cities (Adachi, Kanazawa, Shirakawa, Sendai and Takikawa) on a variety of economic, social, and health conditions. The survey includes over 1,400 questions designed to mirror and ensure comparability with other surveys conducted internationally, such as the Health and Retirement Survey (HRS) in the United States, the Survey of Health, Aging and Retirement in Europe (SHARE), and the English Longitudinal Study of Aging (ELSA) in the United Kingdom. JSTAR is widely considered to be Japan's first globally comparable panel data on the elderly (Ichimura, Shimizutani et al. 2009). Only a subset of these data (90%) is released for researchers' use. The response rate in the second wave among the respondents from the first wave is about 80% (i.e., an attrition rate of about 20%), with some variation across municipalities (Shimizutani, Fujii et al. 2014).

While only focused on a few municipalities and thus not nationally representative, JSTAR researchers argue that the focus on variations in a large number of individuals in selected municipalities controls for cultural, historical, and policy environment and thus constitutes “a unique approach to examining a variety of topics on aging and retirement and contributes to rethinking a way of sampling survey data” (Ichimura, Shimizutani et al. 2009).

In addition to the prevalence of health conditions, JSTAR also includes detailed self-reported information on physical or mental limitations in performing Activities of Daily Living (ADLs) and Instrumental Activities of Daily Living (IADLs). Furthermore, JSTAR also asks respondents detailed questions on measures of social and intellectual engagement, as well as caregiving and care receiving, both formally at skilled nursing facilities or informally through friends and family members.

Because JSTAR includes respondents only up to the age of 77, we supplement our data analysis with data provided by the Nihon University Japanese Longitudinal Study of Aging (NUJLSOA) dating from 1999 and 2001, with 1,921 respondents over age 80. NUJLSOA also includes detailed information on ADLs and IADLs, but has only 14 of the 19 health conditions available in JSTAR.

We choose the following sample selection criteria. Individuals must be at least 45 years old. This yields 3,862 respondents with a total of 7,724 interview years. We then drop observations of individuals with a missing value for any of our health measures of interest. Following this selection criterion, we arrive at the final estimation sample consisting of 2,526 individuals for 2007, 2,659 for 2009, and 1,854 individuals and 3,708 interview years for the pooled JSTAR data. For the 80+ cohort in the NUJLSOA data, the same exclusion criteria led to a total of 1,921 survey respondents and 3,842 respondent-years. Most missing data occur for self-reported health states. The summary statistics for the JSTAR study sample in 2007 are presented in Appendix Table 1.

4. Methods

Based on the work by Goldman, Shang, Bhattacharya et al (2005), the Future Elderly Model (FEM) is a demographic and economic simulation model designed to predict the future health status of the elderly and explore what current trends or future shifts imply for policy. The FEM is a state-transition microsimulation model that permits direct modeling of competing mortality risks. It also permits counterfactual analyses of hypothetical scenarios, such as the implications of a smoke-free or obesity-free population on health and mortality, by replacing the model parameters with alternative values. We present an abridged discussion of the FEM below, and include only our main policy-relevant simulation results from the state-transition model in the main text. A detailed description of the evaluation and construction of the FEM is provided in the Technical Appendix.

4.1 Health Transition Model

This section describes the steps taken to estimate individual health transition models for the Japan FEM. The JSTAR and NUJLSOA data provide self-reported health status measures. We use logistic regressions to estimate the probability of transitioning to each of 19 health conditions in 2009 based on not having that health condition in 2007 and controlling for demographic and comorbid conditions in 2007.

Because these health states are measured by responses to questions such as "Have you ever been told by a doctor ...." we treat all health status states as absorbing states. However, we separately estimated the likelihood of transitioning out of the disease states but found little evidence of recovery for the listed medical conditions in our sample. As a result, we only model transitions into these states (without allowing for cure) in the following form: $ln\left(\frac{p_{i,j,t+2}}{1-p_{i,j,t+2}}\right) = \beta_0 + \boldsymbol{\gamma} \cdot \boldsymbol{X_{ijt}} + \varepsilon_{ijt}$, where $p_{i,j,t+2}$ is the probability of having the *j*-th condition for individual *i* at time *t+2* (2009 (JSTAR), 2001 (NUJLSOA)) conditional on not having the *j*-th condition at time *t*; and $\mathbf{X_{ijt}}$ are demographic characteristics (demeaned age, demeaned age squared, and where appropriate, an indicator for BMI ≥ 23.5, and an indicator for heavy smoking, defined as > 20 cigarettes per day) and co-morbidities for individual *i* in time *t* (2007 (JSTAR) or 1999 (NUJLSOA)) that affect the onset of condition *j*.

The probabilities of the onset of the various conditions are assumed to be linear in the covariates. Age, age squared, and male gender enter into all transition models, but the other covariates enter into the regression only if two medical doctors agree that they are likely causative factors in the onset of the specific disease model in question. Given the low prevalence of obesity in Japan, we choose a BMI value of 23.5 and greater to be a proxy for overweight. For smoking, because of the high number of smokers among Japanese males, we set the indicator variable for smoker if the respondent answers smoking 20 or more cigarettes per day in 2007.

The unit of observation is the interview-pair. All independent variables are measured with a two-year lag, and represent the respondent's characteristics as of 2007 (JSTAR) or 1999 (NUJLSOA). Transition probabilities are estimated only using individuals who did not suffer from a specific condition at baseline. As a result, the sample sizes for various health status transition regressions vary. Using data from JSTAR as an example, consider a respondent who was interviewed in 2007 without cancer but with a heart condition. In 2009, he is diagnosed with cancer. This person's baseline condition included "heart disease," so he does not contribute to the heart disease transition model in any way. On the other hand, he contributes one observation to the cancer transition model. Because JSTAR had only two time points during construction of the health state-transition matrix, we ignore clustering standard errors at the individual level because any given person will contribute at most one observation to a specific disease model.

4.2 Disability Models

Previous Future Elderly Models that simulate the impact of medical treatments on utilization and costs generally contain proxies of physical health such as functional limitations or disability, in addition to the presence of chronic diseases. A common measure of disability consists of a series of questions that are closely linked to activities that involve social roles, particularly those deemed necessary to meet an individual's personal daily living needs, e.g. eating, bathing, and dressing. These are known as Activities of Daily Living (ADLs). A closely related construct, or Instrumental Activities of Daily Living (IADLs), includes higher-level activities, such as managing finances and shopping for groceries.

Measures of ADLs in the JSTAR survey data follow closely the standard definition used in the HRS family of surveys. JSTAR includes questions on whether respondents are able to dress themselves, walk around in their room, bathe, eat, get in and out of bed, and use Western-style toilets. We use the number of ADLs performed with difficulty as the outcome variable of interest, defined as 0, 1, 2, and 3 or more. Measures of IADLs are captured by seven questions that ask whether respondents are able to take public transportation alone, shop for daily necessities, prepare daily meals, pay bills, handle their own banking, make telephone calls and take medications. Again, we use 0, 1, 2, and 3 or more IADLs performed with difficulty as the outcome variable.

Four additional questions each pertain to the survey respondents' social interactions (visiting friends, being called on for advice, visiting sick friends, and initiating conversations with younger individuals) and intellectual activities (filling out pension forms, reading the newspaper, reading books or magazines, and taking interest in the news). For these two measures of societal function as well, we use four categories for the outcome variable, i.e., having difficulty with 0, 1, 2, or 3+ functions. Finally, we code as dichotomous variables whether respondents received any type of help, any help for physical care, and any help for household chores from friends or family members.

We project future disability status (number of ADLs, IADLs, social/intellectual tasks performed with difficulty, and the receipt of assistance from friends/family) using ordered logistic regressions for all specifications with 0, 1, 2, and 3+ as the outcome variable, and logistic regression for all specifications with dichotomous outcome variables. The explanatory variables are the full set of covariates as described in the health transition model, including age, gender, weight, smoking status, and a vector of the 19 defined health conditions. Because we pool 2007 and 2009 data, each respondent potentially contributes up to two observations, and we cluster our standard errors at the individual level. These outcome models were used to predict the distribution of Japan's future population with ADLs, IADLs, and receiving assistance through 2040, based on the FEM model projections of health conditions by age and sex among survivors.

To complete the FEM simulation model, we also need to estimate disease-specific mortality rates by age and sex for the Japanese population. The next section describes our methodology for doing so.

4.3 Disease-Specific Mortality Rates

The Japanese vital statistics data provide detailed information on the leading cause of mortality by age and sex. However, there is no information on the number of health conditions that the individual had at the time of death. Only the leading cause of death is reported. Using JSTAR and these mortality data, we developed an algorithm to compute condition-specific mortality rates for each of the 19 conditions, as described in more detail in the Technical Appendix. In brief, we used the iterative proportional fitting (IPF) algorithm to calculate the conditional mortality rates from JSTAR, NUJLSOA, and the Japanese vital statistics data (Statistics Bureau). To calculate the conditional mortality rates, we assume conditional independence of the disease-specific mortalities. In other words, the probability that any given disease is the cause of death does not depend on the other comorbidities that an individual has. Appendix Table 2 illustrates the setup for the IPF algorithm.

5. Results

5.1 Model Calibration Results

Since our primary goal is to project Japan's future elderly health, disability, and need for care, we report all of our state-transition probability matrices (Appendix Table 3a for JSTAR and 3b for NUJLSOA) and estimated condition-specific mortality rates (Appendix Figure 2) in the Technical Appendix. Overall, our specifications produced plausible results, particularly for ages up to 77 (the oldest respondents in the JSTAR dataset in 2007). For example, our transition matrix predicts that greater age, male gender, BMI greater than 23.5, as well as having heart disease, hyperlipidemia, cerebrovascular disease, and liver disease in 2007 are all positively associated with the probability of developing hypertension by 2009. Likewise, having a joint disorder, a broken hip, mental health issues, or dementia are associated with the greatest probabilities of having difficulties in both ADLs and IADLs. We supplement our censored JSTAR data (truncated at 77) using older data (1999-2001) from the NUJLSOA, which includes respondents aged 80 to 97. The disability transition matrices are presented in Appendix Table 4.

Our conditional mortality estimates show that cancer is linked to the highest annual mortality rates for both men and women, followed by cerebrovascular disease/stroke and heart disease. On the other hand, "other" diseases, osteoporosis, and eye disease had the lowest annual mortality rates. In addition, the predicted disease-specific mortality rates closely followed the rates observed in the vital statistics. We also include in the Technical Appendix predictions of Japan's future disease prevalence from our health transition models.

5.2 Population Simulation Model Results

Putting all the pieces together, the Japan FEM can estimate the health status and functioning of Japan's 50+ population into the future. Figure 1 shows the simulated population pyramids for Japanese age 50 and older from 2014 through 2040. We see significant population aging within the over-50 population, combined with overall population decline: a pyramid with a large "base" of 50- and 60-year olds in 2014, and clearly showing the large post-war baby boom, evolves into a more rectangular shape by 2040, with a smaller base, an echo of the baby boom, and larger proportion of oldest-old, especially among women. Figure 2 compares the FEM estimated population to official Japanese governmental projections from the National Institute of Population and Social Security Research (IPSS 2012). Overall, the model matches the official projections quite well.

Figure 1. Projected population pyramid for Japanese 50+ population, 2014-2040

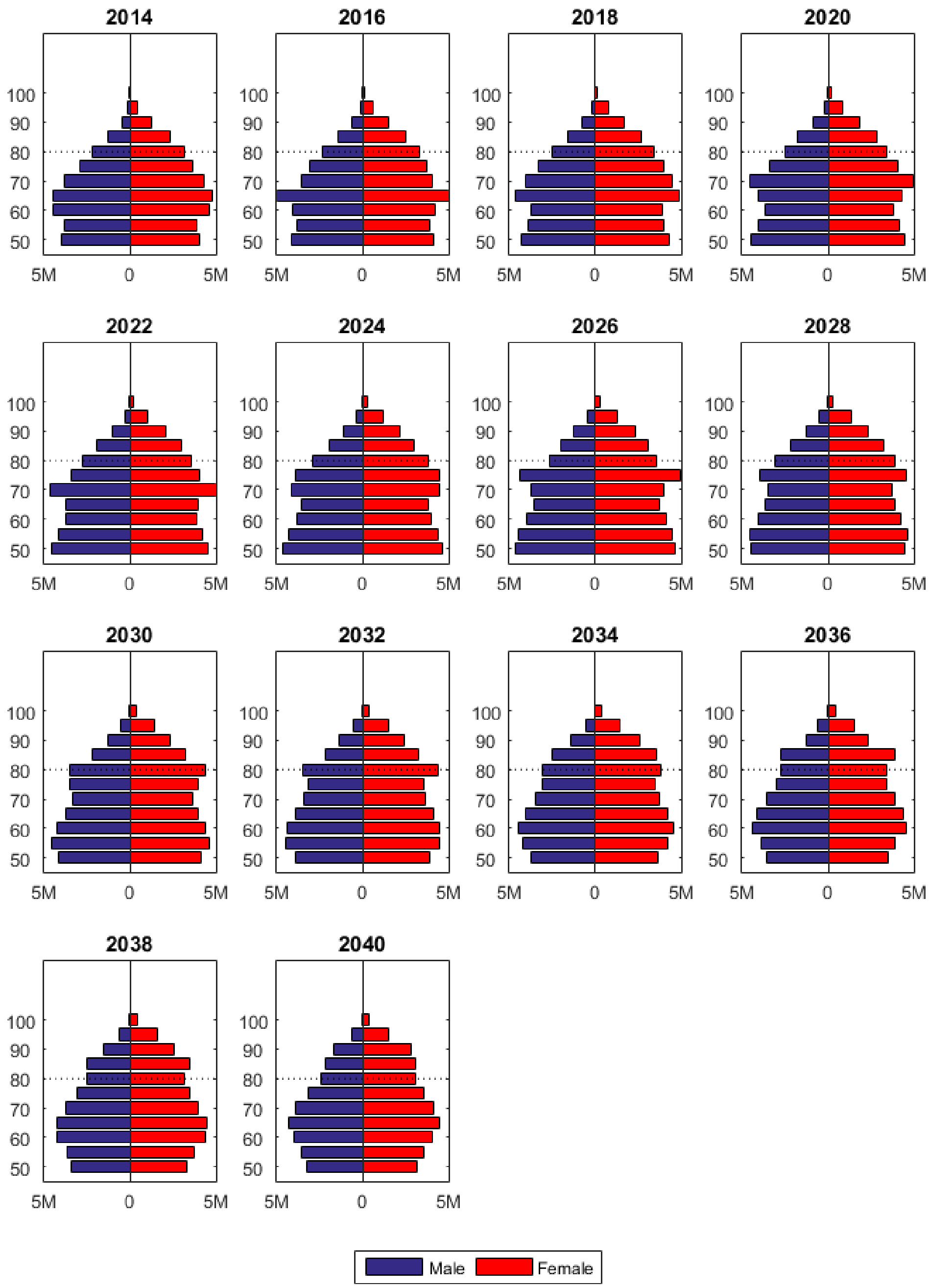
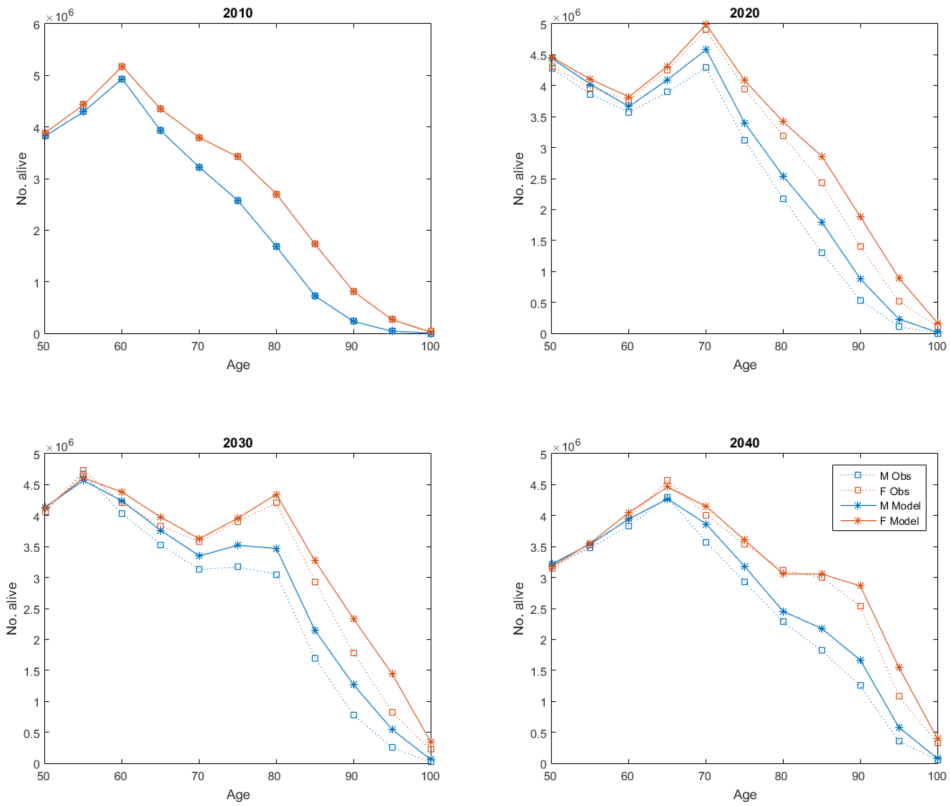


Figure 2. Comparing the FEM Estimated Population to Official Projections, 2010-2040



Our projections portend rising disability among the elderly in Japan. Using our 4 measures of disability, we project how the population with 0, 1, 2, 3 or more disabilities will evolve over the 2014-2040 period. As shown in Figure 3, the predicted prevalence of no difficulty with activities of daily living decreases sharply with age, and the prevalence of difficulty with 3 or more ADLs increases sharply with age, with only moderate changes in the age pattern of disability by simulation year. Similar patterns arise for IADLs (Figure 4) as well as for cognitive/intellectual disabilities and social functioning disabilities (not shown). Therefore the prevalence of disabilities among the future elderly (Figure 5a) is largely driven by the evolution of the age structure among the 50+ population towards a greater proportion of oldest-old with a larger share of disability, although holding the age distribution constant at the 2010 age distribution reveals that a modest future increase in disability at given age (Figure 5b).

Figure 3. Predicted Prevalence of 0, 1, 2, 3 or more Difficulties with ADLs by Age, 2014-2040

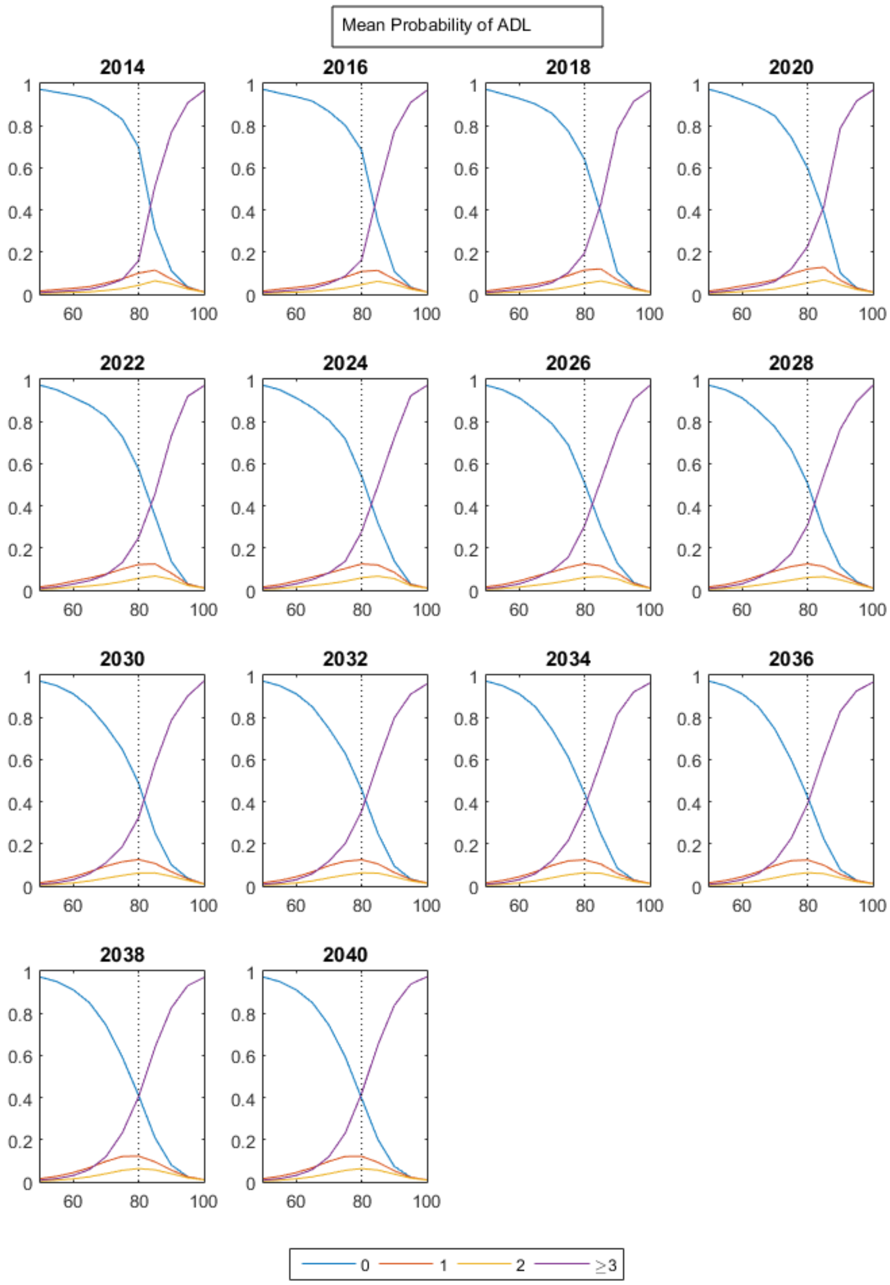


Figure 4. Predicted Prevalence of 0, 1, 2, 3 or more Difficulties with IADLs by Age, 2014-2040

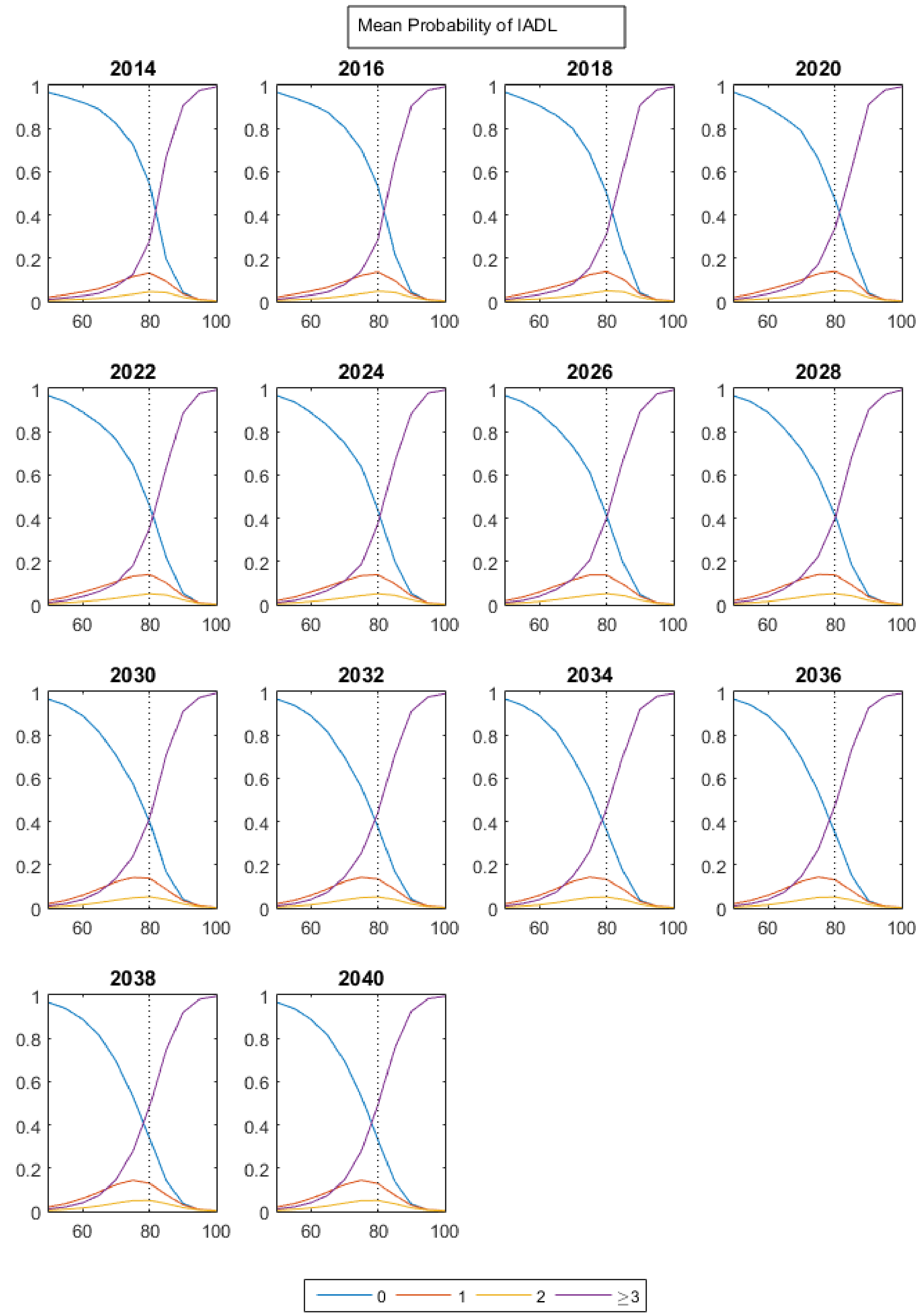


Figure 5a. Estimated Average Population Prevalence of Three or More Disabilities: ADLs, IADLs, Intellectual/Cognitive, or Social Disabilities, 2010-2040

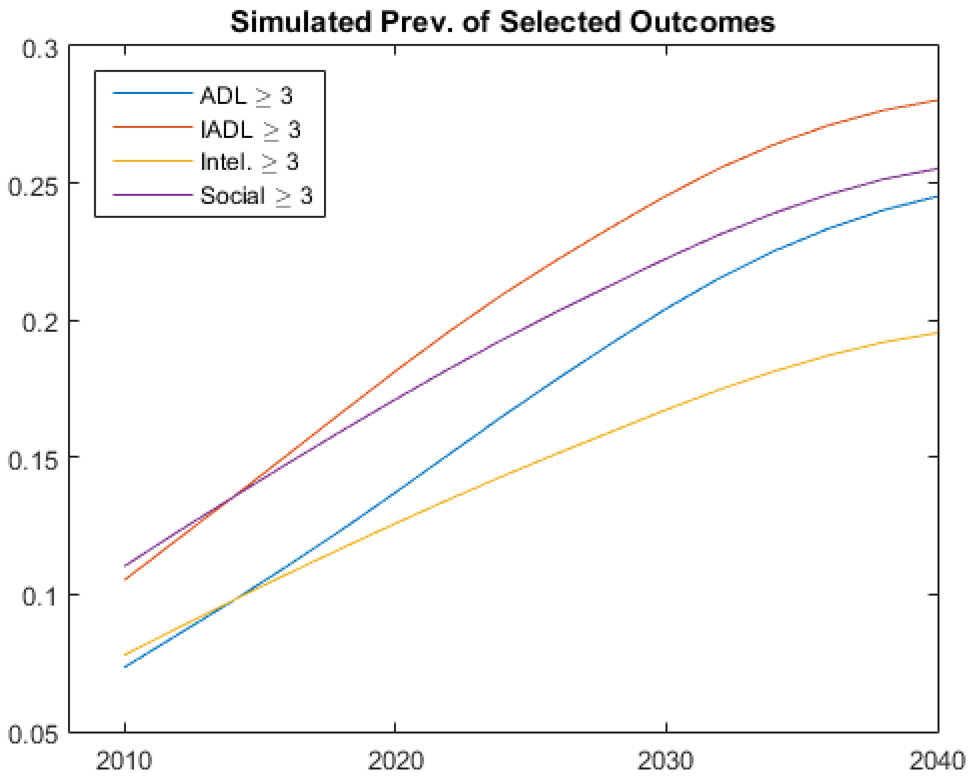
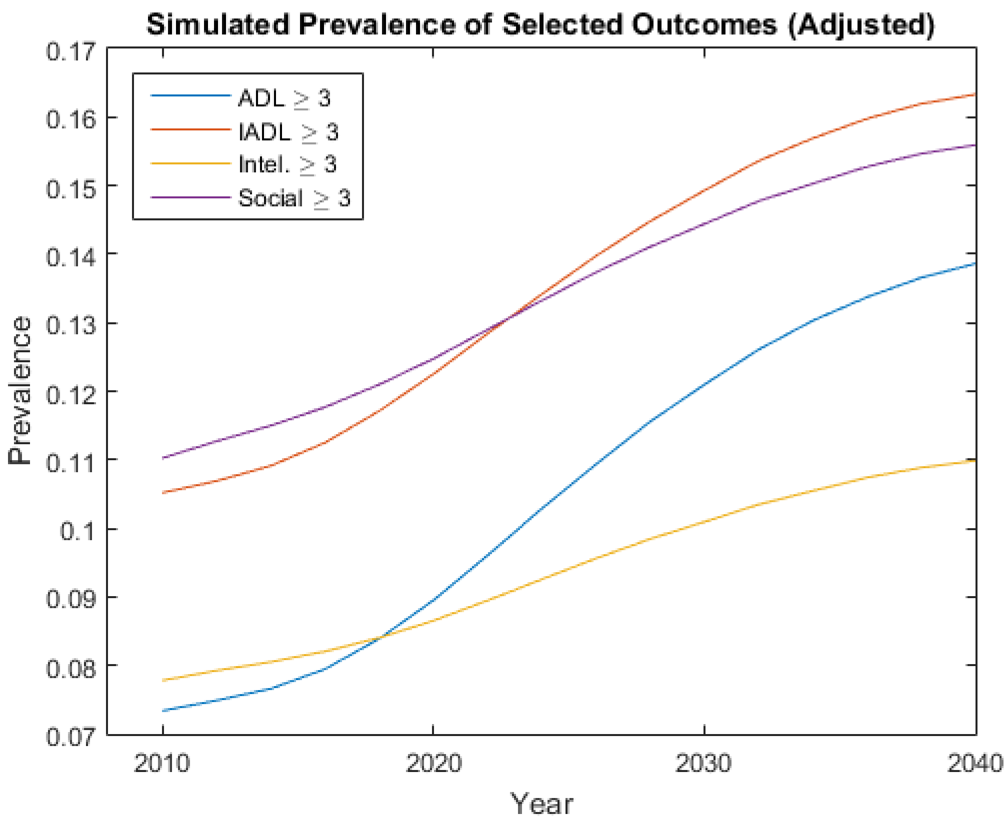
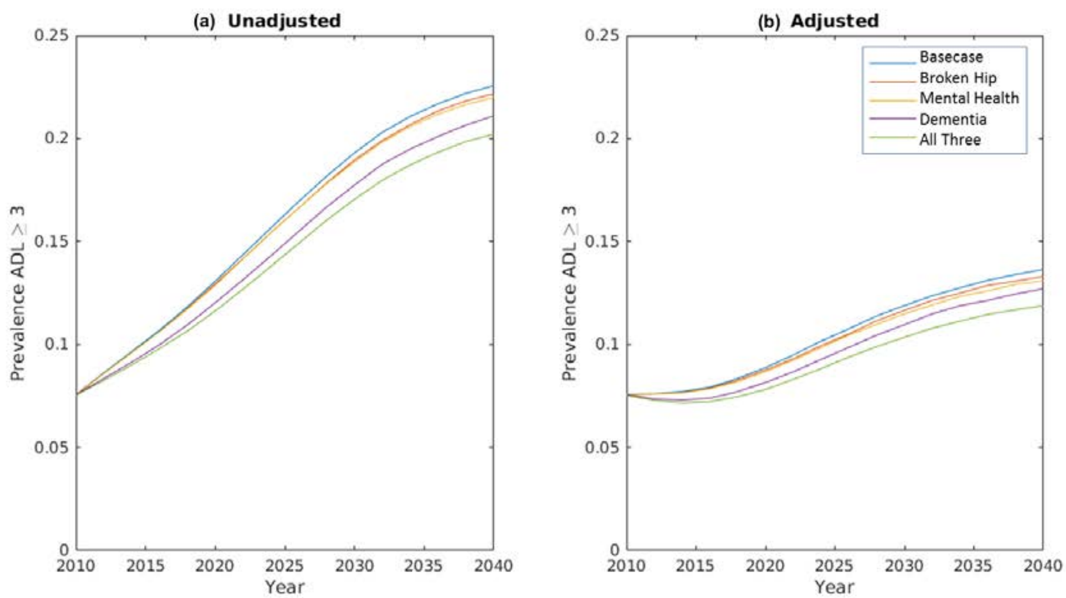


Figure 5b. Estimated Average Population Prevalence of Three or More Disabilities Purely Due to Changing Cohort Health, Holding the Age Distribution Constant at the 2010 Age Distribution



Additional counterfactual simulations further highlight the effect of aging on Japan's future disability burden, and the limited role that primary prevention plays in reducing this burden. By primary prevention, we mean efforts to reduce the probability of transitioning into a disease state from one period to the next. This goal may be achieved, for example, by new medical technology or pharmacological therapeutics that lower the onset of dementia, or by measures to prevent falls and accidents. In Figures 6a and 6b, we show the impact of primary prevention efforts on the prevalence of having difficulty in three or more ADLs, respectively unadjusted and adjusted for age and sex. In Figure 6a, the baseline case represents future disability burden if the probabilities of transitioning into our 19 mutually exclusive comorbid conditions remain unchanged. The lines other than the base case scenario represent what would happen to Japan's future disability burden if we halved the probability of disease transition respectively for broken hip, mental health disorder, dementia, or all three of the medical conditions.

Figures 6a and 6b. Simulated Population Prevalence of Having Three or More Disabilities Given Primary Prevention Measures That Halve the Incidence of Hip Fracture, Mental Disorder, Dementia, or All Three Conditions, Unadjusted (6a) and Adjusted (6b) for Age and Sex

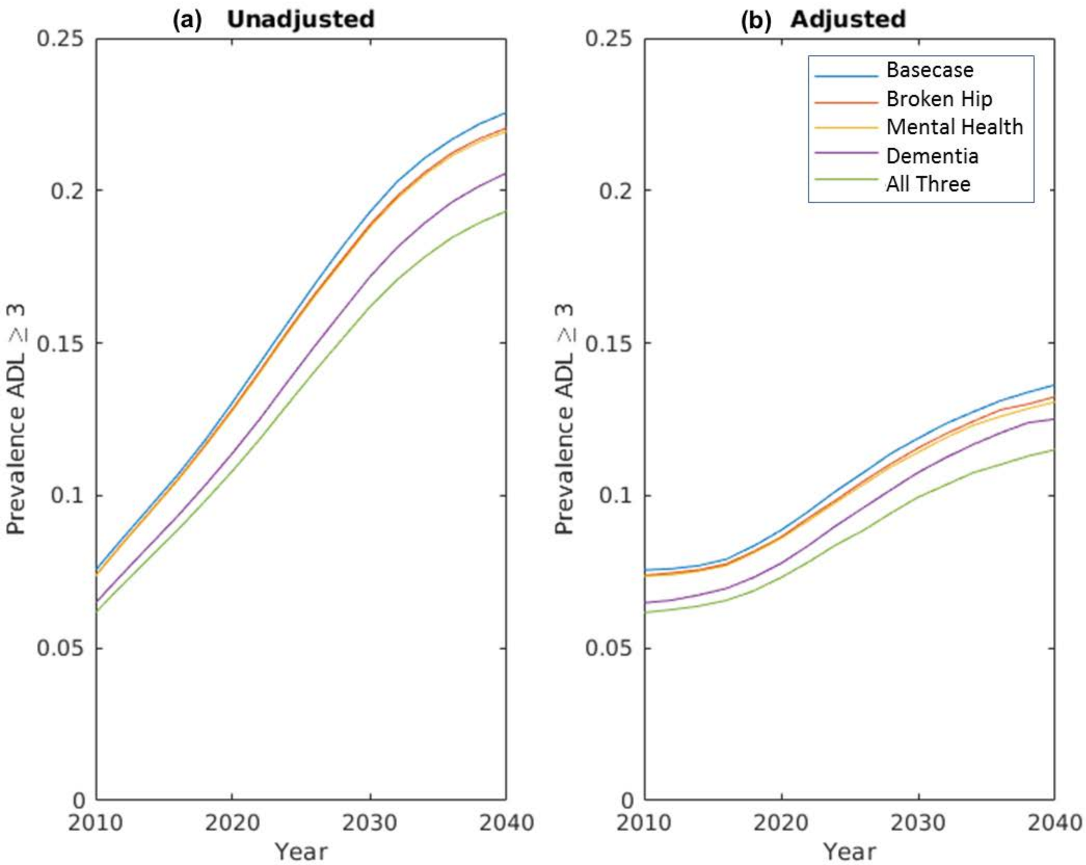


Unsurprisingly, halving the transition probabilities of all three disability-associated comorbid conditions has a greater effect on reducing Japan's future prevalence of disability than reducing the incidence any single one of these three medical conditions. However, if we were to focus on primary prevention on a single medical condition, the figure shows that halving the onset of dementia would have a greater effect of reducing disability burden than reducing the probability of either hip fractures or other mental health disorders alone.

As Figure 6b demonstrates, however, the potential effect on disability of primary prevention pales in comparison with the effect of aging. In every scenario, simply holding Japan's age and sex structure constant at 2010 levels predicts a much lower future disability burden. The prevalence of having difficulty with three or more ADLs would increase over 5% to approximately 13% by 2040 without any primary prevention (blue line, Figure 6b) if Japan's 2040 age and sex structure remains the same as in 2010. By contrast, in the presence of population aging, the prevalence of difficulty with three or more ADLs would increase over 12% to approximately 20% by 2040 (pale green line, Figure 6a) even if medical technology or public health measures reduce the probability of having hip fracture, mental health disorder, and dementia by half.

In Figures 7a and 7b, we present, respectively, the unadjusted and adjusted simulated future disability burden in Japan if secondary prevention measures reduce the probability of disability by 50% given the presence of disease. In other words, instead of preventing the onset of disease, we focus on policies or technologies such as robotic assistance for the elderly with a fractured hip that weaken the association between disease and disability. As the figures show, again the effect of aging overwhelms the potential disability reduction achievable through secondary prevention. In fact, both primary and secondary measures that respectively reduce by 50% the probability of disease onset and the probability of disability given a disease yield similar results. However, secondary prevention reduces the prevalence of disability burden slightly more than primary prevention. Secondary prevention measures also take immediate effect (shown by the immediate separation of the lines in Figures 7a and 7b), whereas primary prevention requires a time lag for a reduction in future disease onset (demonstrated by the gradual separation of the lines in Figures 6a and 6b).

Figures 7a and 7b. Simulated Population Prevalence of Having Three or More Disabilities Given Secondary Prevention Measures That Halve the Probability of Disability in the Presence of Hip Fracture, Mental Disorder, Dementia, or All Three Conditions, Unadjusted (7a) and Adjusted (7b) for Age and Sex



6. Discussion

Our FEM simulation suggests that by 2040, over 27 percent of Japan's elderly will exhibit 3 or more limitations in IADLs and social functioning; almost one in 4 will experience difficulties with 3 or more ADLs; and approximately one in 5 will suffer limitations in cognitive or intellectual functioning. These projections suggest a disturbingly high future burden of disability in Japan. Since the majority of the increase in disability arises from a shift to a more elderly population, prevention efforts that reduce the underlying comorbidities (or future compression of morbidity among middle-aged Japanese) may have only a limited impact on reducing the overall prevalence of disability among Japanese elderly.

Our simulations show a modest increase in disability burden in the future even when we hold Japan's future population age and sex structure at 2010 levels. This result contrasts with findings from other FEM models, and particularly the U.S. model, which predict that disability rates will remain flat after adjusting for age and sex. Our results are likely driven by an increasing prevalence of disability-associated morbidities in Japan's future population, a possible scenario given a trend toward greater survival with multiple comorbidities.

Caution is warranted in comparing these Japanese projected disability rates to those for other countries, since measuring disability comparably across countries is difficult even for international surveys explicitly crafted for comparability like JSTAR, HRS, SHARE, and ELSA. Differential item response analyses suggest that summary indexes (counts of ADL and IADL limitations) likely underestimate mean percentage of population with disability in these international populations (Chan, Kasper et al. 2012). Nevertheless, comparisons can be useful for framing the policy debates and understanding the challenges Japan faces as a super-aging society, including the sustainability of Japan's social programs supporting the elderly, from disability and pensions to health insurance and long-term care insurance.

In the first wave of JSTAR, about 1.3% of the sample (aged 47-77) answered that they were receiving a disability pension at the time of the interview; in the second wave, that number was 1.2% (aged 52–78 (Shimizutani, Fujii et al. 2014)). As shown by Coile, Milligan, and Wise (2014), the share of the population receiving disability benefits at older ages varies substantially across countries (likely due to different eligibility criteria), and is among the lowest in Japan. Their international collaborative research project also demonstrates that international comparisons of disability status are feasible, although Japan's measures from the JSTAR should be interpreted with caution. Analysis of a health index developed by Poterba, Venti, and Wise (1996)-- the first principal component of 25 indicators that are common to the HRS and to all of the

SHARE countries, with overlap in the JSTAR – revealed that the weights across countries were strikingly consistent among all the countries, except for Japan. Nevertheless, in general, the correlations between Japan and the other countries are between 0.88 and 0.93 (Coile, Milligan et al. 2014), suggesting comparability if interpreted with appropriate caution.

According to the National Research Council report "Aging and the Macroeconomy: Long-Term Implications of an Older Population" (Institute of Medicine (US) Committee on the Long-Run Macroeconomic Effects of the Aging US Population 2012), compression of morbidity suggests that older individuals will be active longer. Indeed, self-reported health of 60-year-old men in the 1970s was about the same as for 69-year-olds in the 2000s (NRC 2012:90). The expert committee developed projections of labor supply through 2050, concluding that there would be "very little change in the proportion of the population age 20–74 that could hypothetically supply labor between 2010 and 2050. Individual decisions and public policies may lead to a flat age at retirement in coming decades, but this will not be dictated by health and biology" (Lee 2014) It is far less clear that such a sanguine forecast could be made for Japan, given the projections of health and disability. For example, (Hashimoto, Kawado et al. 2010) estimate that between 1995 and 2004, duration of life with a light or moderate disability increased for both men and women in Japan. Our simulation suggests a substantial further increase as the proportion of the oldest old continues to increase in Japan.

The development of a Future Elderly Model (FEM) for Japan contributes to the literature in a variety of ways. First, such a model has never been estimated for Japan, even though Japan's population aging is far more significant than for the US and most other OECD countries. Second, arguably the need for such a model is especially great for Japan since its health system already features many components—such as universal coverage with strict payment regulation—that limit the ability to further reduce spending growth associated with population aging. Thus Japan's health and long-term care systems are likely to be even more impacted by health trends among the elderly. Third, development of a policy simulation tool like the FEM has already proven to have significance for policy, since in the country of its initial creation – the United States—the FEM has become a leading tool for informing relevant policy debates. Drs. Dana

Goldman and Jay Bhattacharya have collaborated closely to develop and apply the model. The FEM has been presented to the Congressional Budget Office in the US, and has informed some of the CBO thinking on the implications of some elements of health reform (e.g. spending on prevention) on health care expenditures. Drs. Goldman and Bhattacharya are working with the OECD to extend the model to European settings, and to aid European governments in health policy planning.

The model provides a foundation for future simulations of policies to improve the fiscal sustainability of Japan's health care programs in light of its super-aging population. The FEM can also generate projections of how a wide range of health policies, programs, technologies, and services will influence the morbidity, mortality, health spending, long term care use, retirement, labor supply, and earnings of older populations.

7. Limitations and Next Steps

The JSTAR data, although pioneering, also has several limitations, including lack of national representativeness or coverage of the frailest oldest-old population. The health conditions used to estimate health transition probabilities are all self-reported, and are simple dichotomous variables assumed to be absorbing states. We also lack medical expenditures. Medical costs are often conditional on duration of diagnosis, and tend to be highest in the final year of life. To control for these duration effects, we require a level of granularity in the data that is currently not available. In a future iteration of this project, we aim to obtain nationally representative claims records. The results from this preliminary adaptation of the Future Elderly Model to Japan's aging population, however, are based on self-reported health conditions without any information on the year of disease onset.

We also plan to use the highest security version of the JSTAR data that links directly to medical and long-term care spending to conduct simulations using the FEM to inform policy decisions regarding the sustainability of Japan's healthcare spending and long-term care insurance program. Such studies would include simulating the fiscal stability of Japan's long-term care insurance program; analyzing how population aging will impact future health care spending in Japan; and predicting the consequences of extended life expectancy for the prevalence of disability among the Japanese elderly population (i.e., assessing compression of morbidity).

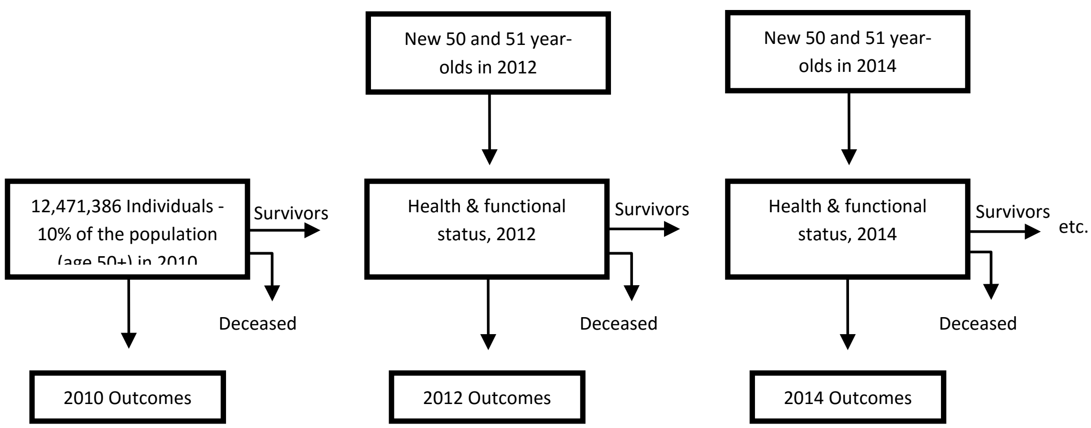
Acknowledgements

This study uses data from the Japanese Study on Aging and Retirement (JSTAR), which was conducted by the Research Institute of Economy, Trade, and Industry (RIETI) and Hitotsubashi University in 2007 and 2009. We thank the JSTAR team for providing access to the data. We also thank the Freeman Spogli Institute for International Studies Japan Fund, the Stanford Center on the Demography and Economics of Health and Aging, and the National Institute on Aging (AG017253) for financial support for this research. Dr. Bhattacharya is grateful for support from the National Institute on Aging for his work on this project (P30 AG017253, R37AG036791 and P01AG05842).

Technical Appendix

Appendix Figure 1 presents an overview of the structure of the microsimulation. The simulation starts in 2010 with nearly 12.5 Million hypothetical individuals age 50+ (10% of the population in 2010; (Statistics Bureau 2010)). The simulation model estimates the risk of developing 19 diseases for each individual. The model updates the health status and mortality risk for each individual. At the end of each cycle, some of the individuals die, and the rest age 2 years and are transitioned to the next cycle. In addition, a new cohort of 50 and 51 year-old individuals are added to the population in 2012 to replenish the youngest cohorts. The same process is repeated for the subsequent cycles (2014, 2016, …, etc.).

Appendix Figure 1: Overview of the microsimulation model



The microsimulation consists of two main modules: a core module that describes the health and mortality of the population, and a set of secondary modules that forecast disability and may be adapted to other outcomes such as healthcare utilization, medical spending, and long-term care in Japan. The secondary modules are based on the core module. This technical appendix focuses on the functionality of the core health transition module. (Jalal, Eggleston et al. 2015)

The core module describes the health status of each individual. Health status is defined by 19 conditions based on self-reported health conditions in JSTAR. The survey asks respondents about a multiplicity of health conditions. Self-reported measures of health conditions are based on a positive response for current or past treatment for a medical condition, or from communication by a physician that the respondent has that specific health condition. We focus our analysis on diseases identified by our medical panel as the most relevant and costly in a Japanese population. The 19 conditions selected are presented in Appendix Table 1, along with their prevalence calculated by using the 2007 data.

Appendix Table 1: Summary Statistics

Variable	Obs	Mean
heart disease	3,708	0.13
hypertension	3,708	0.44
hyperlipidemia	3,708	0.16
CVD	3,708	0.05
diabetes	3,708	0.15
COPD	3,708	0.02
asthma	3,708	0.04
liver	3,708	0.05
ulcer	3,708	0.09
joint	3,708	0.08
broken hip	3,708	0.01
osteoporosis	3,708	0.06
eye disease	3,708	0.14
bladder	3,708	0.05
mental health	3,708	0.03
dementia	3,708	0.00
skin	3,708	0.04
cancer	3,708	0.04
other	3,708	0.16

The model's main variables are AGE_{it}, $GENDER_{i}$, $SMOKE_{it}$, BMI_{it}, and a set of 19 indicator variables $DISEASE_{it}$ = {$DISEASE1_{it}$,...,$DISEASE19_{it}$} that reference the 19 chronic conditions, where i indexes the individual and t refers to time. In addition, we create an indicator variable $MORT_{it}$ = 1 if the simulated individual dies during the simulation. The baseline cohort is defined at the initial time period (t=1). This time period represents the first two years of the simulations (i.e.,2010 and 2011). The variables AGE, GENDER, SMOKE, BMI and DISEASE are sampled from JSTAR with replacement. These samples are repeated until the number of individuals in each age and sex category are equal to the Japanese population distribution in 2010 (Statistics Bureau 2010),

After establishing the baseline cohort, the microsimulation iterates to the next time period (t=2) by projecting the values of each variable for the next two years (i.e., 2012 and 2013). Thus, the variable $AGE_{it=2} = AGE_{it=1} + 2$. Since the 50 and 51 years individuals age to 52 and 53 years-old, respectively, at t=2, new 50 and 51 year-old individuals are added to the simulation to replenish the youngest age group. The characteristics of these new individuals are sampled with replacement from the 50-55 year-old individuals in JSTAR, weighted by the age- and gender-specific projected population of 50 year-olds based on the official Japanese projections (National Institute of Popoulation and Social Security Research 2012).

Health transitions

JSTAR provides self-reported health status measures for each individual in 2007 and 2009. We use logistic regressions to estimate the probability of transitioning to one of the 19 mutually exclusive health states in 2009 based on not having that health condition in 2007 and controlling for demographic and comorbid conditions in 2007. We project transitions of self-reported heart disease, hypertension, hyperlipidemia, diabetes, cancer, and fourteen other categories of disease. The independent variables include health status and basic demographic characteristics such as age, gender, smoking status or weight category, as measured at baseline in 2007. The coefficient estimates of these transitions models predict health status two years into the future (2009). We model these relationships as $H_t + 2 = g(H_t, X_t)$, using multivariate logistic regression. Because these health states are measured by responses to questions such as “Have you ever been told by a doctor ....” we treat all health status states as absorbing states.

We choose the following sample selection criteria. Individuals must be at least 45 years old. This yields 3,862 respondents with a total of 7,724 interview years. We then drop observations of individuals with a missing value for any of our health measures of interest. Following this selection criterion, we arrive at the final estimation sample consisting of 2,526 individuals for 2007, 2,659 for 2009, and 1,854 individuals and 3,708 interview years for the pooled data. Most missing data occur for self-reported health states. The health status measures include heart disease, hypertension, hyperlipidemia, cerebrovascular disease, diabetes, chronic obstructive pulmonary disease, asthma, liver disease, ulcer, joint disease, bone fractures/broken hip, osteoporosis, eye disease, bladder disease, mental health disorder, dementia, skin disease, cancer and all other diseases. Appendix Table 1 provides summary statistics of the baseline 2007 values of the independent variables used in the estimation, including the prevalence of the various disease states.

As noted previously, we treat all health conditions in JSTAR as absorbing states. For the 19 health states, the JSTAR questions are worded as “Have you been newly diagnosed with, or have you ever been diagnosed with ...” The question wordings define these conditions as absorbing states. In addition, we separately estimated the likelihood of transitioning out of the disease states but found little evidence of recovery for the listed medical conditions in our sample. As a result, we only model transitions into these states (without allowing for cure) in the following form: $ln\left(\frac{p_{i,j,t+2}}{1-p_{i,j,t+2}}\right) = \beta_0 + \boldsymbol{\gamma} \cdot \boldsymbol{X_{ijt}} + \varepsilon_{ijt}$, where $p_{i,j,t+2}$ is the probability of having the *j*-th condition for individual *i* at time *t+2* (2009); and $\mathbf{X_{ijt}}$ are demographic characteristics (demeaned age, demeaned age square, and where appropriate, an indicator for BMI $\geqslant$ 23.5, and an indicator for heavy smoking, defined as > 20 cigarettes per day) and co-morbidities for individual *i* in time *t* (2007) that affect the onset of condition *j*.

The probabilities of the onset of the various conditions are assumed to be linear in the covariates (except age). Age, age squared, and male gender enter into all transition models, but the other covariates enter into the regression only if two medical doctors agree that they are likely causative factors in the onset of the specific disease model in question. Given the low prevalence of obesity in Japan, we choose a BMI value of 23.5 and greater to be a proxy for overweight. For smoking, because of the high number of smokers among Japanese males, we set the indicator variable for smoker if the respondent answers smoking 20 or more cigarettes per day in 2007.

The unit of observation is an interview-pair (for years 2007-2009). All independent variables are measured with a two-year lag, and represent the respondent's characteristics as of 2007. Transition probabilities are estimated only using individuals who did not suffer from a specific condition at baseline (2007). As a result, the sample sizes for various health status transition regressions do vary. For example, consider a respondent who was interviewed in 2007 without cancer but with a heart condition. In 2009, he is diagnosed with cancer. This person's baseline condition included "heart disease," so he does not contribute to the heart disease transition model in any way. On the other hand, he contributes one observation to the cancer transition model. Because JSTAR currently only has two time points, we ignore clustering at the individual level because any given person will contribute at most once to a specific disease model.

Since JSTAR lacks data on individuals 80 years and older, we used the health transition module to age the JSTAR population, and sampled for those older than 80 years. We recognize this as an important limitation of the data since the number and type of chronic conditions may be different, especially in the later years of life. (The details of the mortality calculations are described below.)

Mortality

At the end of each cycle, the probability of death for each individual is calculated as the sum of disease-specific mortality rates for that age and sex category[1], such that $m_i = \sum_{j=1} r_{asj}$, where m_i is the total mortality rate for individual i and r_{asj} is the mortality rate conditional on age, gender and disease.

We used the iterative proportional fitting (IPF) algorithm to calculate the conditional mortality rates from JSTAR data and the Japanese vital statistics data. The vital statistics provides aggregated information on the cause of death by age and gender, but no information is provided on other comorbidities at the time of death. To calculate the conditional mortality rates, we assume conditional independence of the disease-specific mortalities, such that the probability of any particular disease being the cause of death is independent on the other comorbidities that an individual has. For example if 5% of patients who have only HD die from HD, under conditional independence, 5% of patient with HD+CA are also expected to die from HD. In the latter group, an additional 4% may die from cancer, for example. More formally, we assume that p(HD cause of death|HD) = p(HD casue of death|HD,CA,…). Later we test the effects of this assumption on the mortality rate calculations.

Appendix Table 2 illustrates the setup for the IPF algorithm for a particular age and sex combination. This table illustrates the distribution of individuals with unique disease profiles who are alive or dead due to one of the 19 diseases. For example, $m_{CA}|q_3$ represents the number of individuals who have heart disease and cancer and are expected to die from cancer. The cells that refer to diseases not in the disease profiles are set to zero because we assume that all diseases are observed. The column totals represent the total number of people with each particular disease profile. This data is known from JSTAR and scaled up to match the number of individuals in the population using the census data. Furthermore, the row totals represent the number of individuals who died in 2010 from each condition, and the total number of individuals alive. Since both the column and row margins are known, the IPF algorithm computes the number of people who are expected to die due to each condition for all disease profiles. The IPF converges when the sum of the cells in each row equals the row total and the sum of the cells on the columns are equal the column margin. The disease specific mortality rates (r_{asj}) are then calculated by dividing each column by the column totals.

Appendix Table 2: Setup for the Iterative Proportional Fitting Algorithm

Diseases Profile	Dead due to leading cause					Alive	Total
	HD	HTN	…	CA	Other		
HD	$m_{HD}\|q_1$	0	…	0	$m_{other}\|q_1$	$alive\|q_1$	q_1
HD+HTN	$m_{HD}\|q_2$	$m_{HTN}\|q_2$	…	0	$m_{other}\|q_2$	$alive\|q_2$	q_2
HD+CA	$m_{HD}\|q_3$	0	…	$m_{CA}\|q_3$	$m_{other}\|q_3$	$alive\|q_3$	q_3
…	…	…	…	…	…	…	…
Total	$\sum_i m_{HD}\|q_i$	$\sum_i m_{HTN}\|q_i$	…	$\sum_i m_{CA}\|q_i$	$\sum_i m_{other}\|q_i$	$\sum_i alive\|q_i$	$\sum_i q_i$

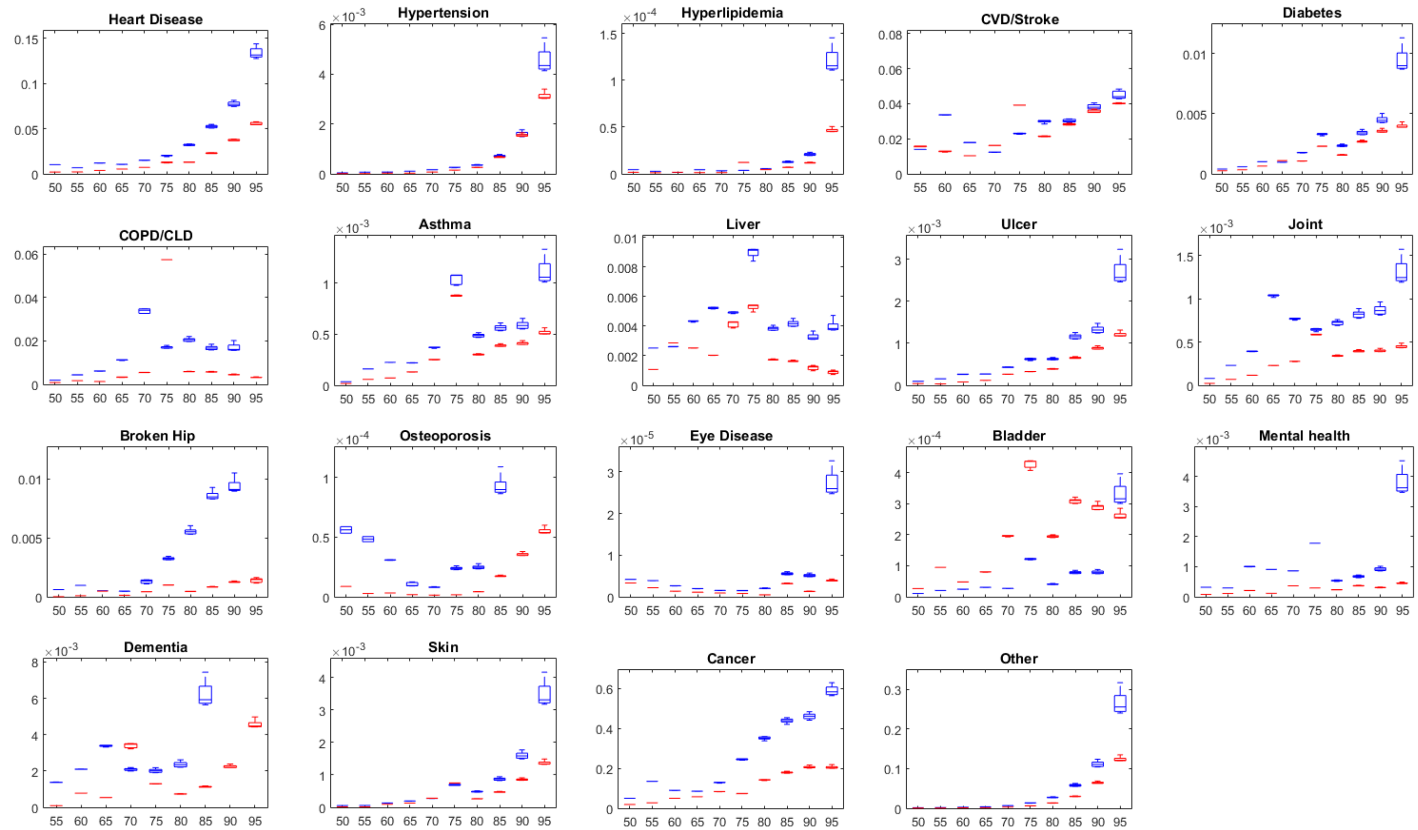
Note: The number in the cells represents the number of people who are expected to live or die from a particular constellation of conditions. The rows represent the combinations of the 19 disease categories in JSTAR; the columns represent the total number projected to die of a particular leading cause of death at a given point in time, as well as the total alive; and the final row shows the total number of deaths due to each of the 19 conditions. HD = heart disease, CA = cancer, HTN = hypertension.

Results

Conditional mortality

Appendix Figure 2 consists of a series of box-plots that illustrate the distribution of age-, sex-, and disease-specific 5-year mortality rates (r_{asj}) predicted with the IPF algorithm for all unique disease profiles. Overall, mortality rates increase with age and are generally higher for males than females except for bladder disease and urinary tract infections. Mortality rates are highest for cancer, followed by "other," a residual category that captures causes of death that are not included in the 18 specific categories and essentially represents the remaining age- and sex-specific mortality rate. Heart disease has the third highest mortality rate. Importantly, the mortality rate distributions over the various disease profiles and comorbidities are narrow, indicating that the conditional mortality independence is a suitable assumption because the mortality rates for the 19 conditions regardless of the associated comorbidities do not seem to vary significantly. In addition, we used the mean r_{asj} over all unique disease profiles to compute the number of people who are expected to die in Japan in 2010.

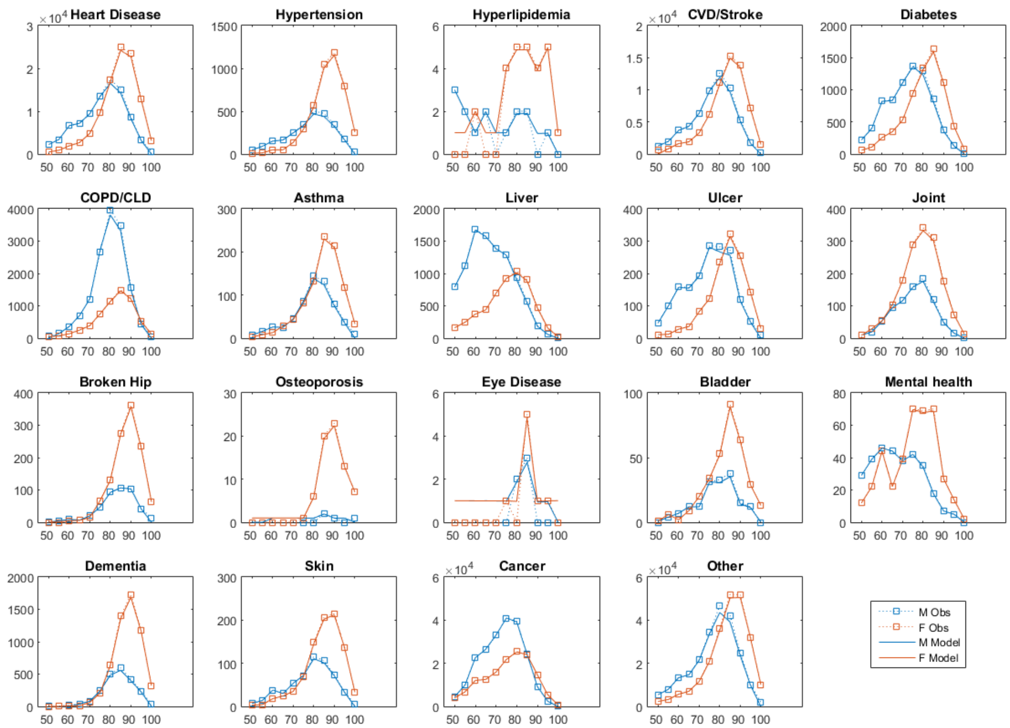
Appendix Figure 2: Age-, gender- and disease-specific mortality rate distributions for all 19 diseases



Note: Blue = male, Red = female. The boxes are the 95% confidence intervals; the central lines are the medians; and the whiskers are the most extreme points.

Appendix Figure 3 compares the IPF predicted deaths (solid line) to the observed data (dashed line). The IPF results are nearly identical to the official observations, indicating that the IPF is capable of accurately reproducing disease-specific mortality.

Appendix Figure 3: Predicted vs. observed number of deaths by age and gender for 2010

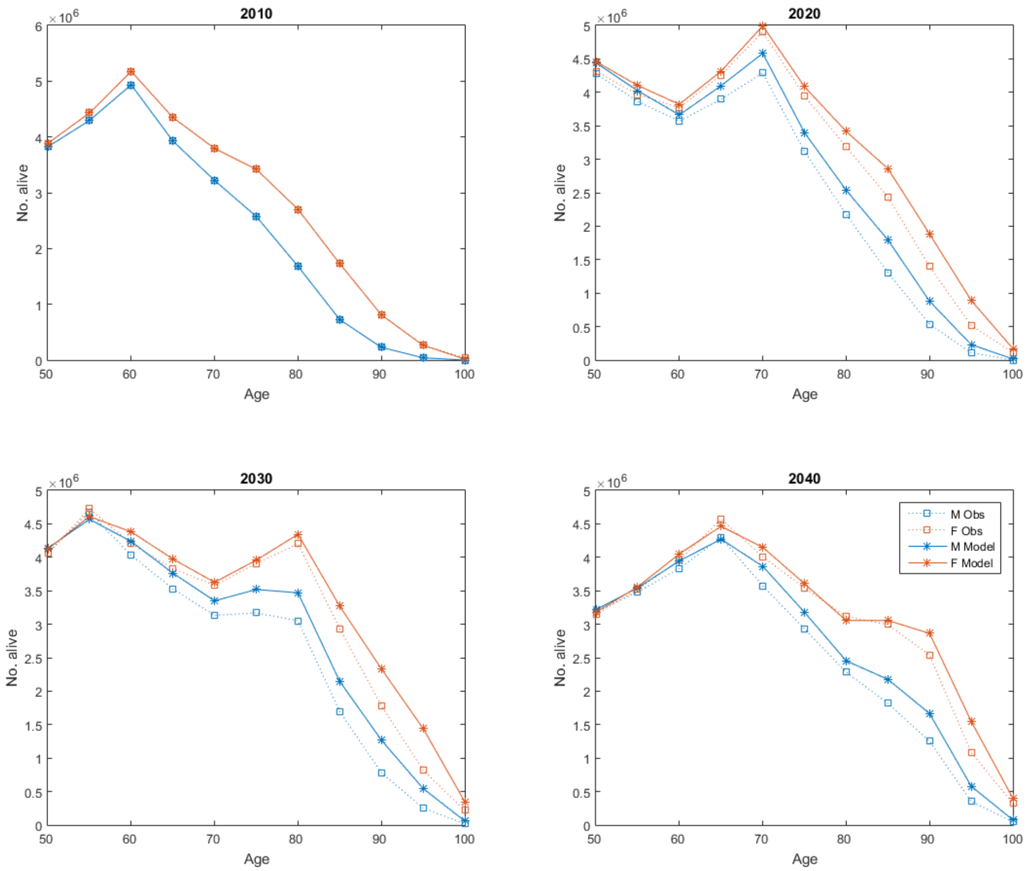


Note: M Obs = observed data for males, F Obs = observed data for females, M Model = IPF prediction for males, F Model = IPF predictions for females.

Population projections

Appendix Figure 4 compares the microsimulation predicted population size (solid line) to the 2010 census and the official Japanese projections for 2020, 2030 and 2040 (dashed line). The baseline results are identical because we are matching the baseline cohort to the 2010 census data. The microsimulation projections in future years are slightly higher than the official projections. The population size is expected to decrease, as shown by the population pyramids (Figure 1), while the relative proportion of the elderly is expected to increase.

Appendix Figure 4: Population size from the microsimulation (solid lines) compared to official projections (dashed lines) for 2020, 2030 and 2040



Note: The official projections are from National Institute of Population and Social Security Research of Japan, median variant. M Obs = observed data for males, F Obs = observed data for females, M Model = IPF prediction for males, F Model = IPF predictions for females. The microsimulation uses the 2010 census population composition. Population Projection for Japan: 2011-2060.

Health transitions

Appendix Tables 3a (JSTAR) and 3b (NUJLSOA) present the results of our conditional health transition model for all 19 health dimensions. Because we include a quadratic term for age, we demean the age variable so that the coefficient on age represents the probability of disease onset with increasing age, and the coefficient on age squared represents whether this rate of change is increasing or decreasing. The coefficients on age are generally positive, signifying that the probability of onset for various conditions tends to increase with age. Coefficients that are negative are often indistinguishable from 0. Likewise for age squared, the coefficients are also generally positive, or, if negative, extremely small and statistically indistinguishable from 0 (except for cancer). This pattern generally indicates that the probability of onset increases with age at an increasing rate. Positive coefficients in Appendix Tables 3a and 3b indicate a higher disease onset probability and thus poorer health. For example, in Appendix Table 3a, having hypertension in 2007 increases the probability heart disease onset in 2009. Having a BMI ≥ 23.5 in 2009 increases the probability of having diabetes in 2009.

All explanatory covariates are measured with a two-year lag, i.e., as of the first interview of the interview-pair in 2007 (or 1999 for NUJLSOA) relative to the second interview in 2009 (or 2001 for NUJLSOA). Note the very powerful cross-effects of comorbid health conditions. For example, hypertension, hyperlipidemia, diabetes, asthma, liver disease, ulcer, osteoporosis, and "other" diseases all increase the risk of developing heart disease. Heart disease, hyperlipidemia, cerebrovascular disease, diabetes, and liver disease are all correlated with the onset of hypertension. Men tend to have higher risks of hypertension, cerebrovascular disease, chronic obstructive pulmonary disease, asthma, ulcer, bladder disease and cancer than women, and lower risks of hyperlipidemia, joint disorder, bone fractures/broken hip, osteoporosis, eye disease, mental health disorders, dementia and skin disease. Being overweight is highly correlated with the onset of hypertension, hyperlipidemia, cerebrovascular disease, diabetes, and joint disorder. Smoking more than 20 cigarettes a day increases the risk of heart disease and diabetes in particular, but does not appear to predict other disease very well. We do not control for a generic "ever smoked" variable because its effects are often contradictory. It is possible that the respondents' answers are particularly inaccurate for this variable. An alternative explanation may be that very high measures of smoking behavior are required to show a health effect in the Japanese context.

Appendix Table 3a: JSTAR Health Transition Matrix

VARIABLES	(1) heart disease 2009	(2) hypertension 2009	(3) hyperlipidemia 2009	(4) CVD 2009	(5) diabetes 2009	(6) COPD 2009	(7) asthma 2009	(8) liver 2009	(9) ulcer 2009	(10) joint 2009
age 2007	0.299	0.248	-0.386	0.120	0.157	1.471	0.796	0.709	-0.907	0.178
	(0.497)	(0.309)	(0.357)	(0.738)	(0.408)	(1.460)	(1.003)	(0.893)	(0.567)	(0.510)
age 2007 squared	-0.00204	-0.00143	0.00288	-0.000182	-0.00122	-0.0107	-0.00541	-0.00511	0.00734*	-0.000996
	(0.00385)	(0.00239)	(0.00281)	(0.00560)	(0.00319)	(0.0110)	(0.00758)	(0.00683)	(0.00441)	(0.00392)
male	-0.368	0.172	-1.010***	0.257	-0.0205	1.504	0.492	-0.561	0.207	-1.034***
	(0.396)	(0.208)	(0.288)	(0.430)	(0.316)	(0.923)	(0.546)	(0.531)	(0.439)	(0.350)
BMI >= 23.5 in 2007		0.804***	0.433	0.387	0.818***			0.436		0.700**
		(0.199)	(0.270)	(0.426)	(0.291)			(0.510)		(0.333)
>= 20 cigarettes/day in 2007	0.600				0.442	0.267				
	(0.414)				(0.354)	(0.766)				
heart disease 2007		0.232				1.196*		0.396		
		(0.257)				(0.721)		(0.596)		
hypertension 2007	0.124			0.673		0.777		0.349		
	(0.331)			(0.433)		(0.709)		(0.507)		
hyperlipidemia 2007	0.343	0.366		0.0477				0.211		
	(0.392)	(0.252)		(0.562)				(0.599)		
CVD 2007		0.557								
		(0.405)								
diabetes 2007	0.840**	0.0746	0.476	0.752					0.746	
	(0.387)	(0.276)	(0.352)	(0.468)					(0.474)	
COPD 2007										
asthma 2007	0.913					3.136***		0.950		
	(0.632)					(0.753)		(0.794)		
liver disease 2007	0.907*	0.677**		1.056*	0.419	1.949**				
	(0.506)	(0.316)		(0.571)	(0.487)	(0.757)				
ulcer 2007	0.559									
	(0.437)									
joint disorder 2007								0.717		
								(0.677)		
broker hip 2007										
osteoporosis 2007	0.646						-0.00223			
	(0.534)						(1.102)			
eye disease 2007									0.539	
									(0.490)	
bladder disease 2007									0.321	
									(0.790)	
mental health 2007									1.987***	
									(0.610)	
dementia 2007							2.568**			
							(1.159)			
skin disease 2007								1.315*		
								(0.783)		
cancer 2007							0	0.989	0.923	0.170
							(0)	(0.783)	(0.769)	(0.617)
other 2007	0.398		0.0801					0.853*		
	(0.343)		(0.297)					(0.497)		
Constant	-14.98	-12.70	9.693	-12.44	-8.908	-57.97	-33.78	-29.88	22.70	-11.04
	(15.88)	(9.901)	(11.23)	(24.13)	(12.92)	(48.24)	(33.05)	(28.99)	(18.04)	(16.47)
Obsverations	1595	1051	1537	1765	1587	1842	1709	1730	1648	1708

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Appendix Table 3a: JSTAR Health Transition Matrix (Continued)

VARIABLES	(11) broken hip 2009	(12) osteoporosis 2009	(13) eye disease 2009	(14) bladder disease 2009	(15) mental health 2009	(16) dementia 2009	(17) skin disease 2009	(18) cancer 2009	(19) other 2009
age 2007	-1.233	0.469	0.162	0.588	-1.180*	1.569	1.029	1.476*	-0.410
	(1.150)	(0.565)	(0.347)	(0.670)	(0.605)	(3.122)	(0.692)	(0.767)	(0.256)
age 2007 squared	0.00962	-0.00310	-0.000642	-0.00360	0.00908*	-0.00924	-0.00785	-0.0112*	0.00331*
	(0.00895)	(0.00432)	(0.00266)	(0.00504)	(0.00479)	(0.0222)	(0.00534)	(0.00590)	(0.00200)
male	-1.774	-2.180***	-0.660***	1.946***	-0.974*	-0.900	-0.638	0.513	-0.262
	(1.232)	(0.493)	(0.240)	(0.487)	(0.535)	(0.692)	(0.416)	(0.402)	(0.195)
BMI >= 23.5 in 2007	0.318	-0.421							-0.0430
	(0.876)	(0.356)							(0.184)
>= 20 cigarettes/day in 2007			0.106						
			(0.310)						
heart disease 2007	1.811*	1.160***	0.635**				0.262		
	(0.963)	(0.367)	(0.249)				(0.510)		
hypertension 2007			0.252						
			(0.213)						
hyperlipidemia 2007									
CVD 2007			0.580						
			(0.357)						
diabetes 2007			0.872***	0.559					
			(0.256)	(0.386)					
COPD 2007									0.565
									(0.529)
asthma 2007	2.049**								
	(0.950)								
liver disease 2007	2.014*		0.273			0.725			
	(1.030)		(0.402)			(1.072)			
ulcer 2007	1.219						0.968**		0.308
	(0.990)						(0.484)		(0.260)
joint disorder 2007									
broker hip 2007		2.314***							1.412**
		(0.840)							(0.685)
osteoporosis 2007	1.545								0.608**
	(0.987)								(0.306)
eye disease 2007									
bladder disease 2007									0.333
									(0.369)
mental health 2007						1.047			
						(1.091)			
dementia 2007									
skin disease 2007									
cancer 2007		0.496		0.405					
		(0.639)		(0.626)					
other 2007		0.753**	0.181				0.860**		
		(0.352)	(0.238)				(0.399)		
Constant	31.80	-20.94	-10.73	-28.41	33.52*	-69.11	-37.88*	-52.80**	10.32
	(36.41)	(18.36)	(11.28)	(22.15)	(18.83)	(109.7)	(22.27)	(24.85)	(8.130)
Obsverations	1,841	1,739	1,567	1,782	1,825	1,873	1,797	1,781	1,360

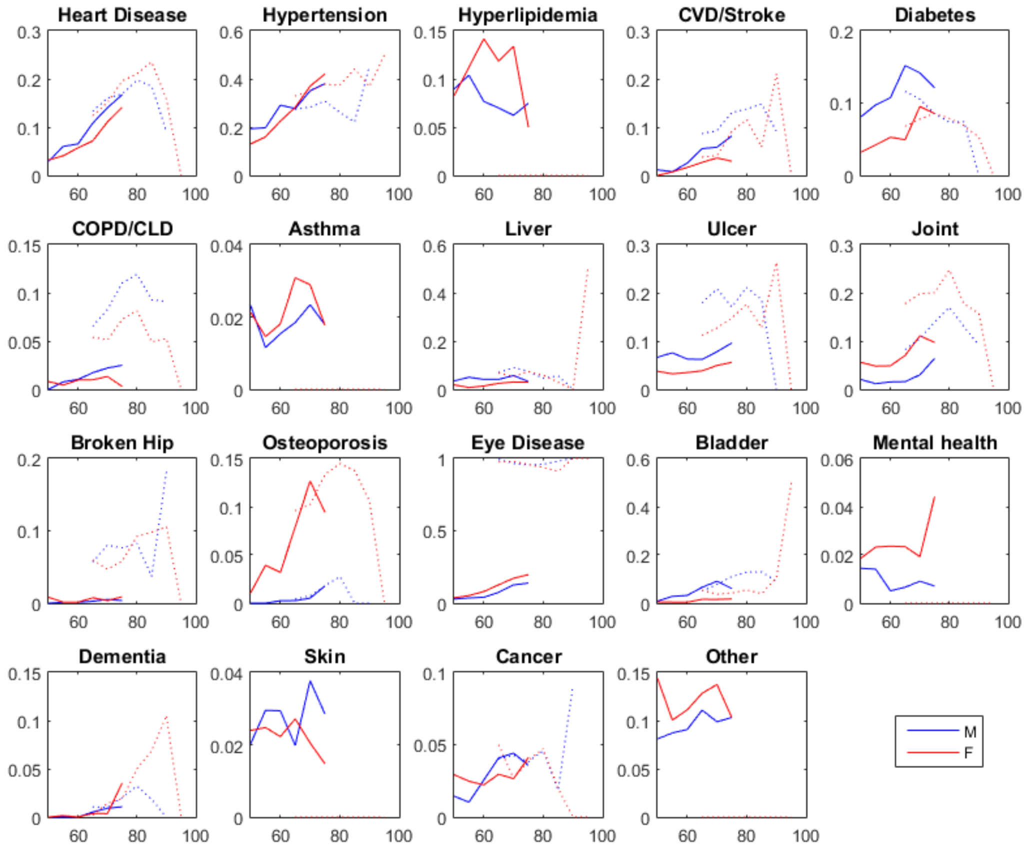
Appendix Table 3b: NUJLSOA Health Transition Matrix

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
VARIABLES	Heart Disease 2001	Hypertension 2001	CVD 2001	Diabetes 2001	Respiratory DIsease 2001	Liver Disease 2001	Arthritis/ Rheumatism 2001	Fractured Hip 2001	Osteoporosis 2001	Cataract/ Glaucoma 2001	Renal/Urinary 2001	Dementia 2001	Cancer 2001
age	0.642	0.905	1.083	-0.693	-0.885	-2.055*	0.207	-0.943	0.701	-4.253	-1.213	-0.813	0.655
	(1.012)	(0.729)	(1.131)	(0.901)	(0.866)	(1.153)	(0.628)	(0.886)	(1.003)	(3.740)	(1.032)	(0.846)	(2.526)
age squared	-0.00402	-0.00518	-0.00623	0.00421	0.00560	0.0123*	-0.000968	0.00599	-0.00421	0.0260	0.00730	0.00568	-0.00441
	(0.00621)	(0.00439)	(0.00687)	(0.00539)	(0.00518)	(0.00688)	(0.00376)	(0.00525)	(0.00610)	(0.0230)	(0.00621)	(0.00501)	(0.0156)
male	-0.0449	-0.160	-0.0407	0.741**	0.196	0.160	-0.739***	-0.989**	-1.914***	-0.783	0.784**	-0.239	0.942*
	(0.284)	(0.228)	(0.319)	(0.308)	(0.402)	(0.564)	(0.264)	(0.395)	(0.384)	(0.734)	(0.373)	(0.362)	(0.522)
bmi235	-0.118	0.414**	-0.359	0.465	-0.0948	-0.549	0.311	-0.240	-0.507*	-1.320**	-0.888**	-0.352	-0.111
	(0.254)	(0.204)	(0.313)	(0.319)	(0.332)	(0.502)	(0.207)	(0.353)	(0.308)	(0.671)	(0.406)	(0.351)	(0.487)
smoker	0.247	-0.153	0.0378	-0.455	0.293	0.206	-0.0234	0.260	0.564*	1.736**	0.105	-0.0833	0.360
	(0.276)	(0.234)	(0.329)	(0.330)	(0.408)	(0.581)	(0.261)	(0.365)	(0.311)	(0.768)	(0.365)	(0.371)	(0.496)
o.heartdisease2000		0.377*			-0.0889	0.389		-0.842*	0.0961	0.276			
		(0.218)			(0.355)	(0.446)		(0.487)	(0.302)	(0.736)			
hypertension2000	0.399*		0.379		-0.145	-0.307				0.774			
	(0.223)		(0.248)		(0.299)	(0.415)				(0.546)			
CVD2000	0.0429	0.839***								0.0533			
	(0.338)	(0.249)								(0.730)			
diabetes2000	-0.0229	-0.176	-0.330							0.150	-0.256		
	(0.385)	(0.371)	(0.512)							(0.728)	(0.605)		
COPD2000													
liver2000	-0.0784	-0.0504	-0.763	-0.334	-0.201			0.530		-0.630		-0.542	
	(0.447)	(0.418)	(0.727)	(0.747)	(0.597)			(0.480)		(0.881)		(0.730)	
digestive2000													
joint2000						-0.294							
						(0.549)							
frachip2000									0.418				
									(0.390)				
osteoporosis2000	0.276							0.513					
	(0.349)							(0.409)					
eyedisease2000													
renal2000													
dementia2000													
cancer2000						-0.159	-0.334		0.670		0		
						(1.050)	(0.549)		(0.500)		(0)		
Constant	-28.26	-41.19	-49.72	24.66	31.59	81.35*	-12.40	33.96	-31.65	173.6	46.68	25.93	-28.94
	(41.23)	(30.22)	(46.48)	(37.61)	(36.14)	(48.22)	(26.14)	(37.25)	(41.13)	(152.1)	(42.72)	(35.61)	(102.1)
Observations	1,352	1,096	1,501	1,538	1,523	1,565	1,356	1,503	1,474	74	1,494	968	1,615

Robust standard errors in parenthese
*** p<0.01, ** p<0.05, * p<0.1

Appendix Figure 5 compares the age- and sex-specific disease prevalence rates for the JSTAR and NUJLSOA, for the medical conditions reported in both datasets. Data on hyperlipidemia, asthma, mental health, skin and “other” health conditions are not available in the NUJLSOA. For the most prevalent conditions, the age-specific prevalence rates are reasonably close, with some indication of compression of morbidity for heart disease, stroke, and ulcers (i.e., for the overlapping age cohorts between 65 and 75, the NUJLSOA shows higher prevalence than the more recent JSTAR cohort). Some of the discrepancies reflect different wording of the questions (e.g. for eye disease). These discrepancies should not impact our projections to a large extent because they are mostly confined to conditions that are not leading causes of death. Nevertheless, a consistent source of data for both the elderly and oldest-old populations would improve the ability to make accurate forecasts.

Appendix Figure 5: Comparing disease prevalence between JSTAR (solid lines) and Nihon University Japanese Longitudinal Study of Aging (NUJLSOA) (dashed lines)



Note: Data on hyperlipidemia, asthma, mental health, skin and "other" health conditions are not available in the NUJLSOA.

Disability

The Japanese population surveyed in JSTAR appears to be relatively healthy based on self-reported ADLs, IADLs, and other measures of social and mental functioning. In Appendix Table 1, we show that 95% of respondents report having no difficulty in ADLs, and 3%, 1%, and 2% respectively reporting difficulties in 1, 2, and 3+ ADLs. For IADLs, these figures are respectively 93% (no IADL), 4% (1 IADL), 1% (2 IADLs), and 2% (3+ IADLs). For social activities, 71% reported having no difficulty, followed by 17%, 7%, and 5% respectively for 1, 2, and 3+ difficulties. For intellectual activities, the figures are respectively 78% (no difficulty), 15% (1 difficulty), 5% (2 difficulties), and 3% (3+ difficulties). Finally, of the 6,328 observations with a non-missing response, 8% reported receiving some sort of help from friends and family, while 22% of 523 non-missing responses reported having received some type of physical assistance, and 42% of 520 non-missing responses reported having received assistance for household chores.

The ordered logistic regressions and logistic regressions show that three chronic illnesses impose the most consistent burden on physical and mental functioning across all measures (ADLs, IADLs, social, intellectual functioning, and care receiving). These illnesses include cerebrovascular disease, diabetes, and dementia; coefficients are particularly large for these three medical conditions (see Appendix Table 4). Other chronic illnesses that adversely impact functioning include heart disease, joint disorder, broken hip, osteoporosis, mental health, and “other” diseases. Joint disorder and broken hip affect ADLs and IADLs in particular, and mental health problems are positively associated with having difficulty with ADLs, IADLs, as well as social and intellectual activities. Older age is also unsurprisingly associated with greater difficulties in physical and mental functioning.

Appendix Table 4: Transition Matrix for Activities of Daily Living (Ordered Logit) / Care Receiving (Logit)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Activities of Daily Living		Other Activities		Received Help from Friends/Family		
VARIABLES	ADL	IADL	Intellectual	Social	Any Help	Physical Care	Chores
age	-0.0402	-0.160	-0.0629	-0.150	-0.209	0.340	0.217
	(0.244)	(0.193)	(0.111)	(0.0991)	(0.144)	(0.334)	(0.305)
age squared	0.000537	0.00175	0.000640	0.00127*	0.00157	-0.00241	-0.00149
	(0.00187)	(0.00147)	(0.000855)	(0.000768)	(0.00112)	(0.00258)	(0.00234)
male	-0.196	0.361**	0.141	0.505***	-0.401***	0.374	-0.187
	(0.181)	(0.150)	(0.0922)	(0.0816)	(0.117)	(0.280)	(0.268)
BMI >= 23.5	0.0794	-0.116	0.0133	-0.114	-0.183	0.420	-0.140
	(0.168)	(0.132)	(0.0802)	(0.0721)	(0.112)	(0.258)	(0.234)
>= 20 cigarettes/day	-0.0146	0.432***	0.399***	0.0645	-0.0775	-0.891*	0.350
	(0.236)	(0.161)	(0.104)	(0.0951)	(0.174)	(0.477)	(0.360)
heart disease	0.492**	0.282*	0.208*	0.202*	0.0947		
	(0.196)	(0.169)	(0.115)	(0.106)	(0.160)		
hypertension	0.242	0.0503		0.0180	0.0454	0.0960	0.368
	(0.170)	(0.135)		(0.0756)	(0.116)	(0.258)	(0.232)
CVD	1.830***	1.164***	1.137***	0.842***	1.520***	1.231***	0.935**
	(0.253)	(0.251)	(0.173)	(0.186)	(0.199)	(0.328)	(0.379)
diabetes	0.794***	0.860***	0.416***	0.361***	0.466***	0.591*	0.498
	(0.200)	(0.160)	(0.114)	(0.102)	(0.153)	(0.309)	(0.314)
COPD	0.234	0.406		0.221	0.590	0.814	0.699
	(0.572)	(0.416)		(0.297)	(0.421)	(0.696)	(0.670)
asthma	0.185	0.175		0.673***	0.0138	0.560	
	(0.409)	(0.340)		(0.167)	(0.322)	(0.640)	
liver	0.264		0.161	0.164	0.119	0.563	0.282
	(0.326)		(0.171)	(0.164)	(0.240)	(0.449)	(0.468)
ulcer	0.144		0.215*	0.0920	0.148	0.877**	0.851**
	(0.263)		(0.127)	(0.120)	(0.195)	(0.368)	(0.354)
joint	1.387***	0.592***	0.147	0.0743	0.719***		0.885**
	(0.213)	(0.218)	(0.154)	(0.141)	(0.167)		(0.366)
broken hip	1.008*	1.923***		0.659	0.170	0.732	1.283
	(0.538)	(0.442)		(0.564)	(0.668)	(1.142)	(1.324)
osteoporosis	0.437	0.409	0.277*	0.332**			
	(0.300)	(0.264)	(0.165)	(0.152)			
eye disease	0.186		0.0975	0.0148			0.641**
	(0.214)		(0.112)	(0.102)			(0.311)
bladder	0.949***	0.00911	0.0575	0.152			-0.0792
	(0.274)	(0.269)	(0.178)	(0.163)			(0.666)
mental health	1.137***	1.535***	1.205***	0.795***	1.185***		
	(0.312)	(0.329)	(0.248)	(0.260)	(0.220)		
dementia	1.903***	3.027***	2.368***	2.429***	1.824***	1.903***	2.573**
	(0.608)	(0.517)	(0.518)	(0.418)	(0.498)	(0.633)	(1.141)
skin	0.313	0.360	0.0930	0.248	0.597***	-0.0975	0.0467
	(0.311)	(0.289)	(0.179)	(0.176)	(0.230)	(0.568)	(0.458)
cancer	0.496	0.427*			0.261	0.420	0.425
	(0.314)	(0.251)			(0.255)	(0.529)	(0.432)
other	0.683***	0.316**	0.259***	0.218***	0.323***	0.281	0.0145
	(0.166)	(0.145)	(0.0891)	(0.0829)	(0.123)	(0.286)	(0.261)
Constant					4.284	-14.07	-8.591
					(4.568)	(10.69)	(9.841)
/Cut1	3.901	0.535	0.391	-2.909			
	(7.927)	(6.289)	(3.553)	(3.171)			
/Cut2	4.765	1.453	1.698	-1.806			
	(7.932)	(6.287)	(3.557)	(3.169)			
/Cut3	5.226	1.822	2.837	-0.802			
	(7.939)	(6.291)	(3.556)	(3.169)			
Observations	5,124	4,921	4,920	4,917	5,099	439	438

Robust standard errors in p

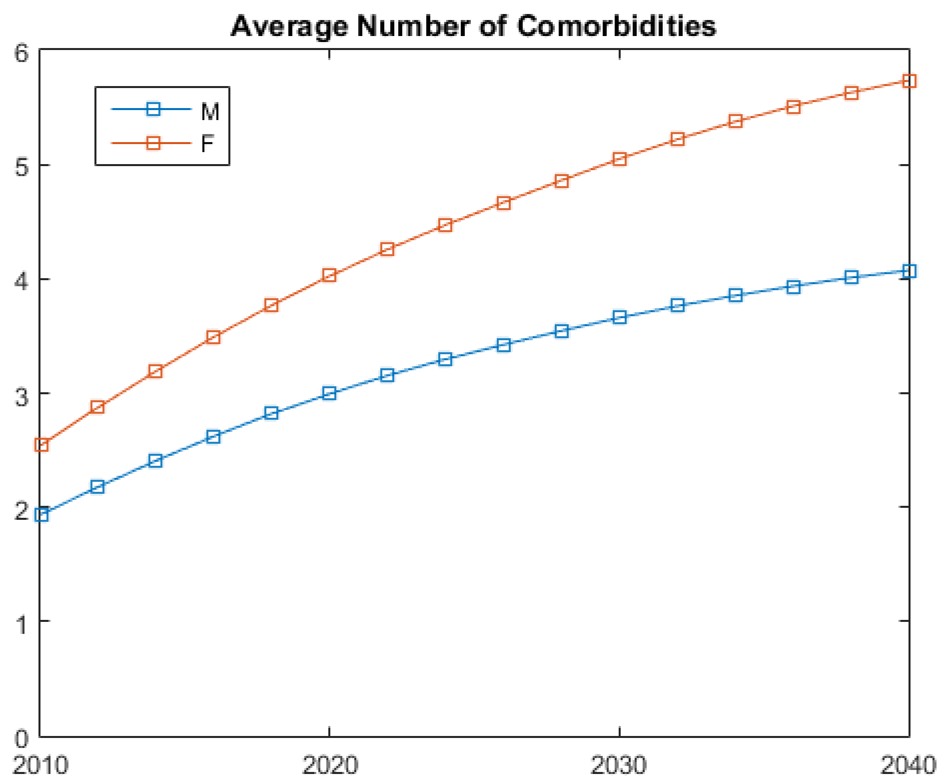
*** p<0.01, ** p<0.05, * p<0

Statistical analyses: Ordered logit for (1)-(4); logit for (5)-(7)

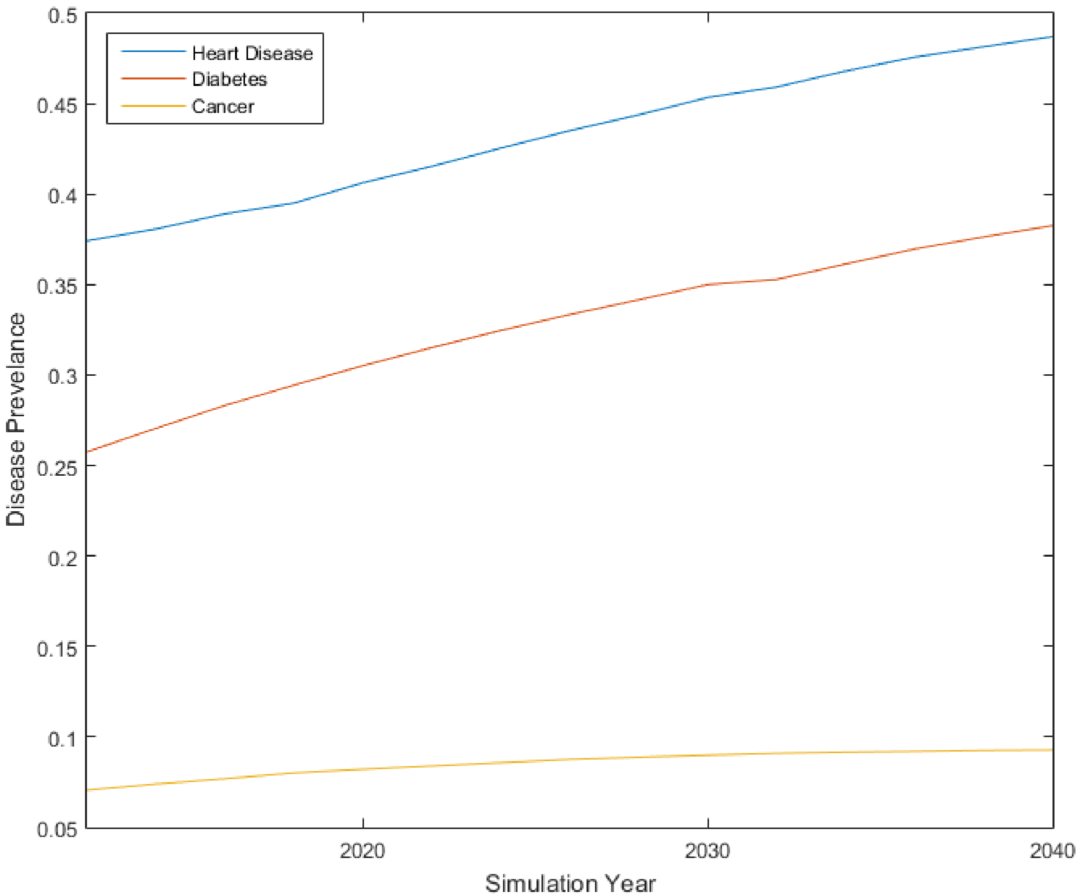
Simulated Prevalence of Diseases

Appendix Figures 6 and 7 show the estimated prevalence of disease for Japan's future population of older adults. The average number of comorbidities per individual is projected to more than double by 2040 (from 2 to 4 for males and 2.6 to 5.7 for females; Appendix Figure 6). Appendix Figure 7 summarizes the average population prevalence of heart disease, diabetes, and cancer among the Japanese population age 50 and older. Cancer prevalence remains around 7-9% throughout the 30-year period; diabetes prevalence increases from 26% to 38% by 2040; and heart disease prevalence increases from 38% to 48%, indicating that almost half of Japanese aged 50 and older will have heart disease by 2040.

Appendix Figure 6: Average number of comorbidities per individual age 50+ for males (blue) and females (red)



Appendix Figure 7: Projected increase in the prevalence of heart disease, diabetes and cancer among Japan's population aged 50 and older, 2010 - 2040



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