

The Health Economics Medical Innovation Simulation:
Technical Documentation - [HRS](#) Version

Precision Health Economics, LLC

May 21, 2019

Contents

1	Functioning of the dynamic model	6
1.1	Background	6
1.2	Overview	7
1.3	Comparison with other prominent microsimulation models of health expenditures	8
1.3.1	Congressional Budget Office Long-Term Model	8
1.3.2	Centers for Medicare & Medicaid Services	9
2	Data sources used for estimation	9
2.1	Health and Retirement Study	10
2.2	National Health Interview Survey	10
2.3	Medical Expenditure Panel Survey	11
2.4	Medicare Current Beneficiary Survey	11
3	Data sources for trends and baseline scenario	12
3.1	Data for trends in entering cohorts	12
3.2	Data for other projections	12
3.3	Demographic adjustments	12
3.3.1	Mortality Projections	13
4	Estimation	13
4.1	Transition model	13
4.1.1	Inverse hyperbolic sine transformation	15
4.2	Quality-adjusted life years	15
4.3	12-Item Short Form Health Survey	16
5	Model for new cohorts	16
5.1	Information available and empirical strategy	16
5.2	Model and estimation	17
6	Government revenues and expenditures	18
6.1	Old-Age and Survivors Insurance benefits	18
6.2	Social Security Disability Insurance benefits	18
6.3	Supplemental Security Income benefits	18
6.4	Medical costs estimation	19
6.5	Taxes	20
7	Scenarios and robustness	20
7.1	Obesity reduction scenario	20
8	Implementation	21
8.1	Intervention module	21
9	Model development	22
9.1	Transition model	22
9.2	Quality-adjusted life years	23
9.2.1	Health-related quality-of-life	23
9.2.2	HRQoL in the MEPS	23

9.2.3	MEPS-HRS crosswalk development	24
9.3	Drug expenditures	26
9.3.1	Drug expenditures - MEPS	26
9.3.2	Drug expenditures - MCBS	26
9.3.3	Drug expenditures - estimation	26
10	Validation	26
10.1	Cross-validation	27
10.2	External validation	27
10.2.1	Benefits from Social Security Administration	27
10.2.2	Benefits from Medicare and Medicaid	28
10.3	External corroboration	28
11	Baseline forecasts	28
11.1	Disease prevalence	28
12	Tables	31
	References	55

List of figures

1	Architecture of THEMIS	9
2	Distribution of EQ-5D index scores for ages 51+ in the 2001–2003 MEPS	24
3	Distribution of SF-12 scores for ages 51+ in the 2003–2012 MEPS	25
4	Historic and forecasted chronic disease prevalence for men 55+	29
5	Historic and forecasted chronic disease prevalence for women 55+	29
6	Historic and forecasted ADL and IADL prevalence for men 55+	30
7	Historic and forecasted ADL and IADL prevalence for women 55+	30

List of tables

1	Health condition prevalences in survey data	32
2	Survey questions used to determine health conditions	33
3	Data sources and methods for projecting future cohort trends	34
4	Projected baseline trends for future cohorts	35
5	Prevalence of obesity, hypertension, diabetes and current smokers among ages 46-56 in 1978 and 2004	36
6	Outcomes in the transition model	37
7	Restrictions on transition model	38
8	Descriptive statistics for exogeneous control variables	39
9	Crossvalidation of 1998 cohort: Simulated vs reported mortality and nursing home outcomes in 2000, 2006, and 2012	40
10	Crossvalidation of 1998 cohort: Simulated vs reported demographic outcomes in 2000, 2006, and 2012	40
11	Crossvalidation of 1998 cohort: Simulated vs reported binary health outcomes in 2000, 2006, and 2012	40
12	Crossvalidation of 1998 cohort: Simulated vs reported risk factor outcomes in 2000, 2006, and 2012	41
13	Crossvalidation of 1998 cohort: Simulated vs reported binary economic outcomes in 2000, 2006, and 2012	41
14	Crossvalidation of 1998 cohort: Simulated vs reported continuous economic outcomes in 2000, 2006, and 2012	41
15	Prevalence of Instrumental Activities of Daily Living (IADL) and Activities of Daily Living (ADL) limitations among ages 51+ in the Medical Expenditure Panel Survey (MEPS) 2001–2003 and HRS 1998–2014	42
16	OLS regressions of EQ-5D utility index among ages 51+ in the MEPS 2001–2003	43
17	OLS regression of the predicted EQ-5D index score against chronic conditions and THEMIS-type functional status specification	44
18	Average predicted EQ-5D and SF-12 scores, age, and prevalence of chronic conditions by functional status for the stock THEMIS simulation sample	45
19	OLS regressions of SF-12 utility score among ages 51+ in the MEPS 2003–2012	46
20	OLS regression of the predicted SF-12 score against chronic conditions and THEMIS-type functional status specification	47
21	Initial conditions used for estimation (1992) and simulation (2010)	48
22	Parameter estimates for latent model: conditional means and thresholds	49
23	Parameter estimates for latent model: parameterized covariance matrix	50

24	Per capita medical spending by payment source, age group, and year	51
25	Simulation results for status quo scenario	51
26	Simulation results for obesity reduction scenario compared to status quo	52
27	Assumptions for each calendar year	53
28	Assumptions for each birth year	54

Acronyms

ACA Affordable Care Act

ADL Activities of Daily Living

AIME Average Indexed Monthly Earnings

BMI Body Mass Index

CBO Congressional Budget Office

CMS Centers for Medicare & Medicaid Services

COLA Cost of Living Adjustment

CPI Consumer Price Index

EQ-5D EuroQol Five Dimensions Questionnaire

FEM Future Elderly Model

GDP Gross Domestic Product

HRQoL Health-Related Quality of Life

HRS Health and Retirement Study

IADL Instrumental Activities of Daily Living

MCBS Medicare Current Beneficiary Survey

MEPS Medical Expenditure Panel Survey

MEPS-HC Medical Expenditure Panel Survey Household Component

NHEA National Health Expenditure Accounts

NHIS National Health Interview Survey

NRA Normal Retirement Age

OASI Old-Age and Survivors Insurance

OECD Organization for Economic Co-operation and Development

OLS Ordinal Least Squares

OOP Out-of-Pocket

PIA Primary Insurance Amount

QALY Quality-Adjusted Life Year

SF-12 12-Item Short Form Health Survey

SGA Substantial Gainful Activity

SSA Social Security Administration

SSDI Social Security Disability Insurance

SSI Supplemental Security Income

THEMIS The Health Economics Medical Innovation Simulation

UK United Kingdom

US United States

1 Functioning of the dynamic model

1.1 Background

The Health Economics Medical Innovation Simulation ([THEMIS](#)) is a microsimulation model originally developed out of an effort to examine health and health care costs among the elderly Medicare population (age 65+). A description of the previous incarnation of the model, called the Future Elderly Model ([FEM](#)), can be found in Goldman et al. [11]. The original work was founded by the Centers for Medicare & Medicaid Services ([CMS](#)) and carried out by a team of researchers composed of Dana P. Goldman, Paul G. Shekelle, Jayanta Bhattacharya, Michael Hurd, Geoffrey F. Joyce, Darius N. Lakdawalla, Dawn H. Matsui, Sydne J. Newberry, Constantijn W. A. Panis and Baoping Shang.

Since then various extensions have been implemented to the original model. The most recent version now projects health outcomes for all Americans aged 51 and older and uses the Health and Retirement Study ([HRS](#)) as a host dataset rather than the Medicare Current Beneficiary Survey ([MCBS](#)). The work has also been extended to include economic outcomes such as earnings, labor force participation and pensions. This work was funded by the National Institute on Aging through its support of the RAND Roybal Center for Health Policy Simulation (P30AG024968), the Department of Labor through contract J-9-P-2-0033, the National Institutes of Aging through the R01 grant “Integrated Retirement Modeling” (R01AG030824) and the MacArthur Foundation Research Network on an Aging Society. Finally, the computer code of the model was transferred from Stata to C++. This report incorporates these new development efforts in the description of the model.

Technical documentation for the RAND [FEM](#) can be found in Goldman et al. [11]. [THEMIS](#) has been developed and derived from an earlier version of the RAND [FEM](#).

1.2 Overview

THEMIS was developed through partnership with government agencies to assess important policy questions. The initial funding came from the **CMS** to develop a model that would assist the trustees of Medicare in analyzing the impact of new medical technologies on the future health, longevity, and health spending of Medicare beneficiaries in the United States (**US**). The output of the **CMS** project was a special issue of *Health Affairs* (published on September 26, 2005), devoted exclusively to the model and its findings. Additional funding from the National Institutes of Health and the US Department of Labor has been used to expand the model to develop additional policy applications.

The model has an extensive record of use by government agencies, Advisory Committees and policymakers to inform decisions. The Congressional Budget Office (**CBO**) has found the output to be a valuable resource when considering microsimulations of the **US** population, economy, and federal budget. The **CBO** also has relied on the model for simulations of various health trends (obesity and smoking). The Committee on National Statistics of the National Research Council highlighted the model in a 2010 publication as the only example of a microsimulation model that can produce health care cost projections, being the largest and most commonly used microsimulation model in the literature [4]. In one influential study, the model was used to estimate the value of a complete cessation of smoking among Medicare beneficiaries [9]. The results of the model demonstrated that this would increase Medicare program spending slightly due to increases in life expectancy that outweigh tobacco-related health spending reductions; these results were used by the **CBO** in considering the effects of potentially raising excise taxes on cigarettes [22]. The National Committee on Vital and Health Statistics of the Department of Health and Human Services Subcommittee on Population Health highlighted how the use of real-world longitudinal data is a key advantage of the model in predicting how individuals transition from one health state to another [5]. In testimony before the **US** Senate Committee on Health Education, results from the model on spending associated with obesity were used to argue for further efforts to reduce obesity in order to slow the rise in health care spending [33].

In addition, the model has an extensive record of publications in high-impact peer-reviewed journals. A study published in the *American Journal of Public Health* in 2009 used the model to analyze the economic impact of several prevention scenarios for obesity, smoking, diabetes, and hypertension, finding that effective prevention could substantially improve the health of Americans, with little or no additional lifetime medical spending [12]. Several studies using the model to examine policies to reduce obesity have been published in high-impact peer-reviewed journals including two studies in *Health Affairs* and one study in the *Journal of Health Economics* on the value of specific medical and pharmaceutical interventions to reduce obesity [8, 15, 20]. Additional work on the fiscal implications of smoking and obesity has been published in the *National Tax Journal* [10], and the *Forum for Health Economics and Policy* [9]. A study published in *Health Affairs* in 2009 examining the effects of different pharmaceutical policies on innovation using the model was awarded the annual Garfield Economic Impact Award for outstanding research that demonstrates how health research impacts the economy [14]. The model has also been used in cancer prevention studies: an article published in *Health Affairs* looked at the economic implications of cancer prevention, drawing conclusions for the financial health of the Medicare program [2]. Another article published in *Health Affairs* by a Centers for Disease Control and Prevention author, used results from the model to conclude that neither technological advances nor improved functional status among the elderly would be likely to relieve budgetary pressures on the Medicare program [17].

The defining characteristic of the model is the modeling of real rather than synthetic cohorts, all of whom are followed at the individual level. This allows for more heterogeneity in behavior

than would be allowed by a cell-based approach. Also, since the [HRS](#) interviews both respondent and spouse, we can link records to calculate household-level outcomes such as net income and Social Security retirement benefits, which depend on the outcomes of both spouses. The omission of the population younger than age 51 sacrifices little generality, since the bulk of expenditure on the public programs we consider occurs after age 50. However, we may fail to capture behavioral responses among the young.

The model has three core components:

- The initial cohort module predicts the economic and health outcomes of new cohorts of 51/52 year-olds. This module takes in data from the [HRS](#) and trends calculated from other sources. It allows us to “generate” cohorts as the simulation proceeds, so that we can measure outcomes for the age 51+ population in any given year.
- The transition module calculates the probabilities of transiting across various health states and financial outcomes. The module takes as inputs risk factors such as smoking, weight, age and education, along with lagged health and financial states. This allows for a great deal of heterogeneity and fairly general feedback effects. The transition probabilities are estimated from the longitudinal data in the [HRS](#).
- The policy outcomes module aggregates projections of individual-level outcomes into policy outcomes such as taxes, medical care costs, pension benefits paid, and disability benefits. This component takes account of public and private program rules to the extent allowed by the available outcomes. Because we have access to data on employer pension plans in the [HRS](#), we are able to realistically model retirement benefit receipt.

Figure 1 provides a schematic overview of the model. We start in 2004 with an initial population aged 51+ taken from the [HRS](#). We then predict outcomes using our estimated transition probabilities (see section 4.1). Those who survive make it to the end of that year, at which point we calculate policy outcomes for the year. We then move to the following time period (two years later), when a new cohort of 51 and 52 year-olds enters (see section 5.1). This entrance forms the new age 51+ population, which then proceeds through the transition model as before. This process is repeated until we reach the final year of the simulation.

1.3 Comparison with other prominent microsimulation models of health expenditures

[THEMIS](#) is unique among existing models that make health expenditure projections. It is the only model that projects health trends rather than health expenditures. It is also the only model that generates mortality out of assumptions on health trends rather than historical time series.

1.3.1 Congressional Budget Office Long-Term Model

The [CBO](#) uses time-series techniques to project health expenditure growth in the short term and then makes an assumption on long term growth. They use a long term growth of excess costs of 2.3 percentage points starting in 2020 for Medicare. They then assume a reduction in excess cost growth in Medicare of 1.5% through 2083, leaving a rate of 0.9% in 2083. For non-Medicare spending they assume an annual decline of 4.5%, leading to an excess growth rate in 2083 of 0.1%.

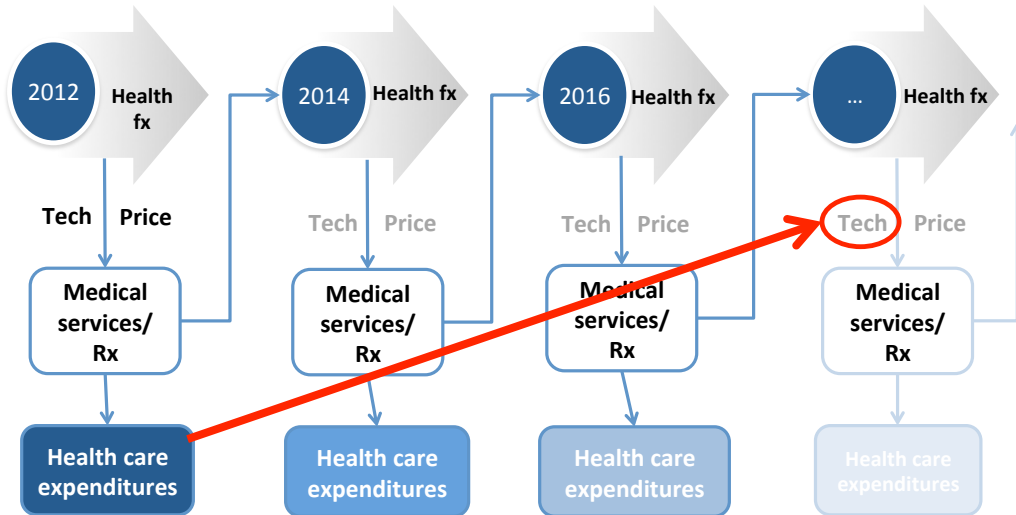


Figure 1: Architecture of THEMIS

1.3.2 Centers for Medicare & Medicaid Services

CMS performs an extrapolation of medical expenditures over the first ten years, then computes a general equilibrium model for years 25 through 75 and linearly interpolates to identify medical expenditures in years 11 through 24 of their estimation. The core assumption they use is that excess growth of health expenditures will be one percentage point higher per year for years 25-75 (that is if nominal Gross Domestic Product (GDP) growth is 4%, health care expenditure growth will be 5%).

2 Data sources used for estimation

The HRS is the main data source for the model. We supplemented this data with health trends and health care costs coming from 3 major health surveys in the U.S. We describe these surveys below and the samples we selected for the analysis. We first list the variables used in the analysis. We then give details on the data sources.

Estimated Outcomes in Initial Conditions Model

Economic Outcomes

Employment
Earnings
Wealth
Defined Contribution Pension Wealth
Pension Plan Type
Averaged Indexed Monthly Earnings
Social Security Quarters of Coverage
Health Insurance

Health Outcomes

Hypertension
Heart Disease
Self-Reported Health
Body Mass Index Status
Smoking Status
Functional Status

Estimated Outcomes in/from Transition Model

Economic Outcomes

Employment
Earnings
Wealth
Demographics
Health Insurance
SSDI Claim
Defined Benefit Claim
SSI Claim
OASI Claim

Health Outcomes

Death
Heart
Stroke
Cancer
Hypertension
Diabetes
Lung Disease
Nursing Home
BMI
Smoking Status
ADL Limitations
IADL Limitations

Other Outcomes

Income Tax Revenue
Social Security Revenue
Medicare Revenue
Medical Expenses
Medicare Part A Expenses
Medicare Part B Expenses
Medicare Part B Enrollment
Medicare Part D Enrollment
OASI Enrollment
SSDI Enrollment
SSI Enrollment
Medicaid Enrollment
Medicaid Expenditures

2.1 Health and Retirement Study

The [HRS](#) waves 2000-2012 are used to estimate the transition model. Interviews occur every two years. We use the dataset created by RAND (RAND [HRS](#), version O) as our basis for the analysis. We use all cohorts in the analysis and consider sampling weights whenever appropriate. When appropriately weighted, the [HRS](#) in 2010 is representative of U.S. households where at least one member is at least 51. The [HRS](#) is also used as the host data for the simulation (pop 51+ in 2010) and for new cohorts (aged 51 and 52 in 2010).

The [HRS](#) adds new cohorts every six years. The latest available cohort was added in 2010, which is why that is [THEMIS](#)'s base year.

2.2 National Health Interview Survey

The National Health Interview Survey ([NHIS](#)) contains individual-level data on height, weight, smoking status, self-reported chronic conditions, income, education, and demographic variables. It is a repeated cross-section done every year for several decades. But the survey design has been

significantly modified several times. Before year 1997, different subgroups of individuals were asked about different sets of chronic conditions, after year 1997, a selected sub-sample of the adults were asked a complete set of chronic conditions. The survey questions are quite similar to that in the [HRS](#). As a result, for projecting the trends of chronic conditions for future 51/52 year-olds, we only use data from 1997 to 2010. A review of survey questions is provided in [Table 2](#). Information on weight and height were asked every year, while information on smoking was asked in selected years before year 1997, and has been asked annually since year 1997.

[THEMIS](#) uses the [NHIS](#) to project prevalence of chronic conditions in future cohorts of 51/52 year olds. The method is discussed in [Sections 3.1](#) and [5.1](#). [THEMIS](#) also relies on the [MEPS](#), a subsample of [NHIS](#) respondents, for model estimation. See [section 2.3](#) for a description.

2.3 Medical Expenditure Panel Survey

The [MEPS](#), beginning in 1996, is a set of large-scale surveys of families and individuals, their medical providers (doctors, hospitals, pharmacies, etc.), and employers across the US. The Medical Expenditure Panel Survey Household Component ([MEPS-HC](#)) provides data from individual households and their members, which is supplemented by data from their medical providers. The [MEPS-HC](#) collects data from a representative sub sample of households drawn from the previous year's [NHIS](#). Since the [NHIS](#) does not include the institutionalized population, neither does the [MEPS](#): this implies that we can only use the [MEPS](#) to estimate medical costs for the non-elderly population. Information collected during household interviews include: demographic characteristics, health conditions, health status, use of medical services, sources of medical payments, and body weight and height. Each year the household survey includes approximately 12,000 households or 34,000 individuals. Sample size for those aged 51-64 is about 4,500. [MEPS](#) has comparable measures of Social Economic Status variables as those in the [HRS](#), including age, race/ethnicity, educational level, census region, and marital status.

[THEMIS](#) uses the [MEPS](#) years 2000-2012 for cost estimation. See [Section 6.4](#) for a description. [THEMIS](#) also uses the [MEPS](#) 2001 data for Quality-Adjusted Life Year ([QALY](#)) model estimation. This is described in [Section 4.2](#).

2.4 Medicare Current Beneficiary Survey

The [MCBS](#) is a nationally representative sample of aged, disabled and institutionalized Medicare beneficiaries. The [MCBS](#) attempts to interview each respondent twelve times over three years, regardless of whether he or she resides in the community, a facility, or transitions between community and facility settings. The disabled (under 65 years of age) and oldest-old (85 years of age or older) are over-sampled. The first round of interviewing was conducted in 1991. Originally, the survey was a longitudinal sample with periodic supplements and indefinite periods of participation. In 1994, the [MCBS](#) switched to a rotating panel design with limited periods of participation. Each fall a new panel is introduced, with a target sample size of 12,000 respondents and each summer a panel is retired. Institutionalized respondents are interviewed by proxy. The [MCBS](#) contains comprehensive self-reported information on the health status, health care use and expenditures, health insurance coverage, and socioeconomic and demographic characteristics of the entire spectrum of Medicare beneficiaries. Medicare claims data for beneficiaries enrolled in fee-for-service plans are also used to provide more accurate information on health care use and expenditures. [MCBS](#) years 1992-2012 are used for estimating medical cost and enrollment models. See [section 6.4](#) for discussion.

3 Data sources for trends and baseline scenario

Two types of trends need to be projected in the model. First, we need to project trends in the incoming cohorts (the future new age 51/52 individuals). This includes trends in health and economic outcomes. Second, we need to project excess aggregate growth in real income and excess growth in health spending (if used).

3.1 Data for trends in entering cohorts

We use a multitude of data sources to compute US trends. First, we use the NHIS for chronic conditions and apply the methodology discussed in Goldman et al. [11]. The method consists of projecting the experience of younger cohorts into the future until they reach age 51. The projection method is tailored to the synthetic cohorts observed in the NHIS. For example, in 1980 we observe a representative sample of age 35 individuals born in 1945. We follow their disease patterns from 1980 to 1981 by then selecting from the survey those aged 36 in 1981, accounting for mortality, etc.

We then collect information on other trends, i.e., for obesity and smoking, from other studies [13, 16, 19, 25, 27]. Table 3 presents the sources and Table 4 presents the trends we use in the baseline scenario. Table 5 presents the prevalence of obesity, hypertension, diabetes, and current smokers in 1978 and 2004, and the annual rates of change from 1978 to 2004. We refer the readers to the analysis in Goldman et al. [11] for information on how the trends were constructed.

3.2 Data for other projections

We make two assumptions relating to real growth in wages and medical costs. Firstly, as is done in the 2009 Social Security Trustees report [30] intermediate cost scenario, we assume a long term real increase in wages (earnings) of 1.1% per year.

When real growth in medical expenditures is incorporated into projections, following CMS, we assume excess real growth in medical costs (that is additional cost growth to GDP growth) as 1.5% in 2004, reducing linearly to 1% in 2033, .4% in 2053, and -.2% in 2083. We also include the Affordable Care Act (ACA) cost growth targets as an optional cap on medical cost growth. Baseline medical spending figures presented assume those targets are met. GDP growth in the near term (through 2019) is based on CBO projections, with the OASDI Trustees assumption of 2% yearly afterwards [30].

In the baseline scenario, THEMIS does not apply these medical expenditure adjustments, nor does it apply the generic mortality improvements associated with those cost increases. This is consistent with the approach of isolating the impact of a single change (e.g. introduction of a novel therapy) to the current standard of care. In those cases where generic improvements to life expectancy would be relevant, the accompanying growth in real expenditures is incorporated as well.

3.3 Demographic adjustments

We make two adjustments to the weighting in the HRS to match population counts. Since we deleted some cases from the data due to missing responses and other data quality concerns, this accounts for selectivity based on these characteristics. First, we post-stratify the HRS sample by 5 year age groups, gender and race and rebalance weights using the Census Bureau 2000-2010 Intercensal Population Estimates. We do this for both the host data set and the new cohorts. We

scale the weights for future new cohorts using 2012 National Population Projections based on race and gender [32]. Second, we post-stratify the HRS sample of deaths between the 2002 and 2004 interview waves by 5 year age groups, gender and race and rebalance weights based on the Human Mortality Database.

Once the simulation begins, trends in migration are applied. We use net migration from the Social Security Administration (SSA) Trustees report intermediate cost scenario [30].

3.3.1 Mortality Projections

Separate mortality rate adjustment factors can be defined for the under and over 65 age groups based on the mortality projections from the 2013 SSA Trustees report. The SSA projections are interpolated through 2090, then extended using generalized least squares regression with log link through 2150.

In the baseline scenario, THEMIS does not apply these mortality adjustments, nor does it apply medical cost growth that would be associated with these improvements. This is consistent with the usual approach of isolating the impact of a single change (e.g. introduction of a novel therapy) to the current standard of care. In those cases where generic improvements to life expectancy would be relevant, these mortality adjustments are applied.

4 Estimation

In this section we describe the approach used to estimate the transition model, the core of the THEMIS, and the initial cohort model which is used to rejuvenate the simulation population.

4.1 Transition model

We consider a large set of outcomes for which we model transitions. Table 6 gives the set of outcomes considered for the transition model along with descriptive statistics and the population at risk when estimating the relationships.

Since we have a stock sample from the age 51+ population, each respondent goes through an individual-specific series of intervals. Hence, we have an unbalanced panel over the age range starting from 51 years old. Denote by j_{i0} the first age at which respondent i is observed and j_{iT_i} the last age when he is observed. Hence we observe outcomes at ages $j_i = j_{i0}, \dots, j_{iT_i}$.

We first start with discrete outcomes which are absorbing states (e.g., disease diagnostic, mortality, benefit claiming). Record as $h_{i,j_i,m} = 1$ if the individual outcome m has occurred as of age j_i . We assume the individual-specific component of the hazard can be decomposed in a time invariant and variant part. The time invariant part is composed of the effect of observed characteristics x_i that are constant over the entire life course and initial conditions $h_{i,j_0,-m}$ (outcomes other than the outcome m) that are determined before the first age in which each individual is observed.¹ The time-varying part is the effect of previously diagnosed outcomes $h_{i,j_i-1,-m}$ on the hazard for m .² We assume an index of the form $z_{m,j_i} = x_i\beta_m + h_{i,j_i-1,-m}\gamma_m + h_{i,j_0,-m}\psi_m$. Hence, the latent component of the hazard is modeled as

$$h_{i,j_i,m}^* = x_i\beta_m + h_{i,j_i-1,-m}\gamma_m + h_{i,j_0,-m}\psi_m + a_{m,j_i} + \varepsilon_{i,j_i,m} \quad (1)$$

¹Section 9.1 explains why the $h_{i,j_0,-m}$ terms are included.

²With some abuse of notation, $j_i - 1$ denotes the previous age at which the respondent was observed.

$$m = 1, \dots, M_0, j_i = j_{i0}, \dots, j_{iT_i}, i = 1, \dots, N$$

The term $\varepsilon_{i,j_i,m}$ is a time-varying shock specific to age j_i . We assume that this last shock is normally distributed and uncorrelated across diseases. We approximate a_{m,j_i} with an age spline. After several specification checks, knots at age 65 and 75 appear to provide the best fit. This simplification is made for computational reasons since the joint estimation with unrestricted age fixed effects for each condition would imply a large number of parameters. The absorbing outcome, conditional on being at risk, is defined as

$$h_{i,j_i,m} = \max\{I(h_{i,j_i,m}^* > 0), h_{i,j_i-1,m}\}$$

the occurrence of mortality censors observation of other outcomes in a current year. Mortality is recorded from exit interviews.

A number of restrictions are placed on the way feedback is allowed in the model. Table 7 documents restrictions placed on the transition model. We also include a set of other controls. A list of such controls is given in Table 8 along with descriptive statistics.

We have three other types of outcomes:

1. First, we have binary outcomes which are not an absorbing state, such as living in a nursing home. We specify latent indices as in Equation (1) for these outcomes as well but where the lag dependent outcome also appears as a right-hand side variable. This allows for state-dependence.
2. Second, we have ordered outcomes. These outcomes are also modeled as in Equation (1) recognizing the observation rule is a function of unknown thresholds ς_m . Similarly to binary outcomes, we allow for state-dependence by including the lagged outcome on the right-hand side.
3. The third type of outcomes we consider are censored outcomes, earnings and financial wealth. Earnings are only observed when individuals work. For wealth, there are a non-negligible number of observations with zero and negative wealth. For these, we consider two part models where the latent variable is specified as in Equation (1) but model probabilities only when censoring does not occur. In total, we have M outcomes.

The parameters $\theta_1 = \left(\{\beta_m, \gamma_m, \psi_m, \varsigma_m\}_{m=1}^M\right)$ can be estimated by maximum likelihood. Given the normality distribution assumption on the time-varying unobservable, the joint probability of all time-intervals until failure, right-censoring or death conditional on the initial conditions $h_{i,j_0,-m}$ is the product of normal univariate probabilities. Since these sequences, conditional on initial conditions, are also independent across diseases, the joint probability over all disease-specific sequences is simply the product of those probabilities.

For a given respondent observed from initial age j_{i0} to a last age j_{T_i} , the probability of the observed health history is (omitting the conditioning on covariates for notational simplicity)

$$l_i^{-0}(\theta; h_{i,j_{i0}}) = \left[\prod_{m=1}^{M-1} \prod_{j=j_{i1}}^{j_{T_i}} P_{ij,m}(\theta)^{(1-h_{ij-1,m})(1-h_{ij,M})} \right] \times \left[\prod_{j=j_{i1}}^{j_{T_i}} P_{ij,M}(\theta) \right]$$

We use the -0 superscript to make explicit the conditioning on $\mathbf{h}_{i,j_{i0}} = (h_{i,j_{i0},0}, \dots, h_{i,j_{i0},M})'$. We have limited information on outcomes prior to this age. The likelihood is a product of M terms with the m th term containing only $(\beta_m, \gamma_m, \psi_m, \varsigma_m)$. This allows the estimation to be done separately for each outcome.

4.1.1 Inverse hyperbolic sine transformation

One problem fitting the wealth and earnings distribution is that they have a long right tail and wealth has some negative values. We use a generalization of the inverse hyperbolic sine transform presented in MacKinnon and Magee [18]. First denote the variable of interest y . The hyperbolic sine transform is

$$y = \sinh(x) = \frac{\exp(x) - \exp(-x)}{2} \quad (2)$$

The inverse of the hyperbolic sine transform is

$$x = \sinh^{-1}(y) = h(y) = \log(y + (1 + y^2)^{1/2})$$

Consider the inverse transformation. We can generalize such transformation, first allowing for a shape parameter θ ,

$$r(y) = h(\theta y) / \theta \quad (3)$$

Such that we can specify the regression model as

$$r(y) = x\beta + \varepsilon, \varepsilon \sim N(0, \sigma^2) \quad (4)$$

A further generalization is to introduce a location parameter ω such that the new transformation becomes

$$g(y) = \frac{h(\theta(y + \omega)) - h(\theta\omega)}{\theta h'(\theta\omega)} \quad (5)$$

where $h'(a) = (1 + a^2)^{-1/2}$.

We specify Equation (4) in terms of the transformation g . The shape parameters can be estimated from the concentrated likelihood for θ, ω . We can then retrieve β, σ by standard Ordinal Least Squares (OLS).

Upon estimation, we can simulate

$$\tilde{g} = x\hat{\beta} + \sigma\tilde{\eta}$$

where η is a standard normal draw. Given this draw, we can retransform using Equation (5) and Equation (2)

$$\begin{aligned} h(\theta(y + \omega)) &= \theta h'(\theta\omega)\tilde{g} + h(\theta\omega) \\ \tilde{y} &= \frac{\sinh[\theta h'(\theta\omega)\tilde{g} + h(\theta\omega)] - \theta\omega}{\theta} \end{aligned}$$

4.2 Quality-adjusted life years

As an alternative measure of life expectancy, we compute a **QALY** based on the EuroQol Five Dimensions Questionnaire (**EQ-5D**) instrument, a widely-used Health-Related Quality of Life (**HRQoL**) measure.³ The scoring system for **EQ-5D** was first developed by Dolan [6] using a United Kingdom (**UK**) sample. Later, a scoring system based on a U.S. sample was generated [29]. The **HRS** does not ask the appropriate questions for computing **EQ-5D**, but the **MEPS** does. We use a crosswalk from **MEPS** to compute **EQ-5D** scores for **HRS** respondents.⁴

THEMIS has a more limited specification of functional status than what is available in the **HRS**. In order to predict **HRQoL** for the **THEMIS** simulation sample, we needed to build a bridge

³Section 9.2.1 gives some background on **HRQoL** measures.

⁴Section 9.2.2 describes **EQ-5D** in the **MEPS**. Details of the crosswalk model development are given in 9.2.3.

between **THEMIS** functional status and the **EQ-5D** score imputed into **HRS**. We used **OLS** to model the **EQ-5D** score predicted for 1998–2014 **HRS** respondents as a function of the seven chronic conditions, the **THEMIS** specification of functional status, and self-reported health. The results are shown in Table 17.

The **EQ-5D** scoring method is based on a community population. Following a suggestion by Emmett Keeler,⁵ if a person is living in a nursing home, the **QALY** is reduced by 10%. We used the parameter estimates in Table 17 to predict **EQ-5D** scores for the entire simulation sample and reduced nursing home residents’ score by 10%. The resulting scores are representative of the U.S. population (both in community and in nursing homes) aged 51 and over. Table 18 summarizes the **EQ-5D** score using this model for the stock simulation sample in 2010.

4.3 12-Item Short Form Health Survey

In addition to **QALY** based on the **EQ-5D** instrument, we compute 12-Item Short Form Health Survey (**SF-12**), a widely-used **HRQoL** measure. The **SF-12** questionnaire and scoring system was first developed by Ware et al. [34], and updated in year 2002 [35]. Similar to the calculation of **EQ-5D** instrument, we use a crosswalk from **MEPS** to compute **SF-12** scores.⁶ We then estimate an **OLS** regression to model the **SF-12** score predicted for 1998–2014 **HRS** respondents as a function of eight chronic conditions, the **THEMIS** specification of functional status, and self-reported health. The results are shown in Table 20. Table 18 summarizes the **SF-12** score using this model for the stock simulation sample in 2010.

5 Model for new cohorts

We first discuss the empirical strategy, then present the model and estimation results. The model for new cohorts integrates information coming from trends among younger cohorts with the joint distribution of outcomes in the current population of age 51 respondents in the **HRS**.

5.1 Information available and empirical strategy

For the transition model, we need to first to obtain outcomes listed in Table 21. Ideally, we need information on

$$f_t(y_{i1}, \dots, y_{iM}) = f_t(\mathbf{y}_i)$$

where t denotes calendar time, and $\mathbf{y}_i = (y_{i1}, \dots, y_{iM})$ is a vector of outcomes of interest whose probability distribution at time t is $f_t(\cdot)$. Information on how the joint distribution evolves over time is not available. Trends in conditional distributions are rarely reported either.

Generally, we have (from published or unpublished sources) good information on trends for some moments of each outcome (say a mean or a fraction). That is, we have information on $g_{t,m}(y_{im})$, where $g_{t,m}(\cdot)$ denotes the marginal probability distribution of outcome m at time t .

For example, we know from the **NHIS** repeated cross-sections that the fraction of individuals that is obese is increasing by roughly 2% a year among 51 year-olds. In statistical jargon this means we have information on how the mean of the marginal distribution of y_{im} , an indicator variable that denotes whether someone is obese, is evolving over time.

⁵personal correspondance.

⁶Section 9.2.2 describes **SF-12** in the **MEPS**. Details of the crosswalk model development are given in 9.2.3.

We also have information on the joint distribution at one point in time, say year t_0 . For example, we can estimate the joint distribution on age 51 respondents in the 1992 wave of the [HRS](#), $f_{t_0}(\mathbf{y}_i)$.

We make the assumption that only some part of $f_t(\mathbf{y}_i)$ evolves over time. In particular, we will model the marginal distribution of each outcome allowing for correlation across these marginals. The correlations will be assumed fixed while the mean of the marginals will be allowed to change over time.

5.2 Model and estimation

Assume the latent model for $\mathbf{y}_i^* = (y_{i1}^*, \dots, y_{iM}^*)'$

$$\mathbf{y}_i^* = \boldsymbol{\mu} + \boldsymbol{\varepsilon}_i,$$

where $\boldsymbol{\varepsilon}_i$ is normally distributed with mean zero and covariance matrix $\boldsymbol{\Omega}$. It will be useful to write the model as

$$\mathbf{y}_i^* = \boldsymbol{\mu} + \mathbf{L}_\Omega \boldsymbol{\eta}_i$$

where \mathbf{L}_Ω is a lower triangular matrix such that $\mathbf{L}_\Omega \mathbf{L}'_\Omega = \boldsymbol{\Omega}$ and $\boldsymbol{\eta}_i = (\eta_{i1}, \dots, \eta_{iM})'$ are standard normal. We observe $y_i = \Gamma(y_i^*)$ which is a non-invertible mapping for a subset of the M outcomes. For example, we have binary, ordered and censored outcomes for which integration is necessary.

The vector $\boldsymbol{\mu}$ can depend on some variables which have a stable distribution over time \mathbf{z}_i (say race, gender and education). This way, estimation preserves the correlation with these outcomes without having to estimate their correlation with other outcomes. Hence, we can write

$$\boldsymbol{\mu}_i = \mathbf{z}_i \boldsymbol{\beta}$$

and the whole analysis is done conditional on \mathbf{z}_i .

For binary and ordered outcomes, we fix $\Omega_{m,m} = 1$ which fixes the scale. Also we fix the location of the ordered models by fixing thresholds as $\tau_0 = -\infty$, $\tau_1 = 0$, $\tau_K = +\infty$, where K denotes the number of categories for a particular outcome. We also fix to zero the correlation between selected outcomes (say earnings) and their selection indicator. Hence, we consider two-part models for these outcomes. Because some parameters are naturally bounded, we also re-parameterize the problem to guarantee an interior solution. In particular, we parameterize

$$\begin{aligned} \Omega_{m,m} &= \exp(\delta_m), \quad m = m_0 - 1, \dots, M \\ \Omega_{m,n} &= \tanh(\xi_{m,n}) \sqrt{\Omega_{m,m} \Omega_{n,n}}, \quad m, n = 1, \dots, N \\ \tau_{m,k} &= \exp(\gamma_{m,k}) + \tau_{k-1}, \quad k = 2, \dots, K_m - 1, m \text{ ordered} \end{aligned}$$

and estimate the $(\delta_{m,m}, \xi_{m,n}, \gamma_k)$ instead of the original parameters. The parameter values are estimated using the *cmp* package in Stata [26]. Table 22 gives parameter estimates for the indices, while Table 23 gives parameter estimates of the covariance matrix in the outcomes.

To apply trends to the future cohorts, the latent model is written as

$$\mathbf{y}_i^* = \boldsymbol{\mu} + \mathbf{L}_\Omega \boldsymbol{\eta}_i.$$

Each marginal has a mean change equal to $E(\mathbf{y} \mid \boldsymbol{\mu}) = (1 + \tau)g(\boldsymbol{\mu})$, where τ is the percent change in the outcome and $g()$ is a non-linear but monotone mapping. Since it is invertible, we can find the vector $\boldsymbol{\mu}^*$ where $\boldsymbol{\mu}^* = g^{-1}(E(\mathbf{y} \mid \boldsymbol{\mu})/(1 + \tau))$. We use these new intercepts to simulate new outcomes.

6 Government revenues and expenditures

This gives a limited overview of how revenues and expenditures of the government are computed. These functions are based on 2004 rules, but we include predicted changes in program rules such changes based on year of birth (e.g., Normal Retirement Age ([NRA](#))).

We cover the following revenues and expenditures:

Revenues	Expenditures
Federal Income Tax	OASI benefits
State and City Income Taxes	SSDI benefits
Social Security Payroll Tax	SSI benefits
Medicare Payroll Tax	Medical Care Costs
Property Tax	Medicaid
	Medicare (parts A, B, and D)

6.1 Old-Age and Survivors Insurance benefits

Workers with 40 quarters of coverage and of age 62 are eligible to receive their retirement benefit. The benefit is calculated based on the Average Indexed Monthly Earnings ([AIME](#)) and the age at which benefits are first received. If an individual claims at his [NRA](#) (65 for those born prior to 1943, 66 for those between 1943 and 1957, and 67 thereafter), he receives his Primary Insurance Amount ([PIA](#)) as a monthly benefit. The [PIA](#) is a piece-wise linear function of the [AIME](#). If a worker claims prior to his [NRA](#), his benefit is lower than his [PIA](#). If he retires after the [NRA](#), his benefit is higher. While receiving benefits before reaching [NRA](#), earnings are taxed above a certain earning disregard level. An individual is eligible to half of his spouse's [PIA](#), properly adjusted for the claiming age, if that is higher than his/her own retirement benefit. A surviving spouse is eligible to the deceased spouses [PIA](#). Since we assume prices are constant in our simulations, we do not adjust benefits for the Cost of Living Adjustment ([COLA](#)) which usually follows inflation. We however adjust the [PIA](#) bend points for increases in real wages.

6.2 Social Security Disability Insurance benefits

Workers with enough quarters of coverage and under the normal retirement age are eligible for their [PIA](#) (no reduction factor) if they are judged disabled (which we take as the predicted outcome of Social Security Disability Insurance ([SSDI](#)) receipt) and earnings are under a cap called the Substantial Gainful Activity ([SGA](#)) limit. This limit was \$9720 in 2004. We ignore the 9 month trial period over a 5 year window in which the [SGA](#) is ignored.

6.3 Supplemental Security Income benefits

Self-reported receipt of Supplemental Security Income ([SSI](#)) in the [HRS](#) provides estimates of the proportion of people receiving [SSI](#) under what other estimates would suggest. To correct for this bias, we use a probit of receiving [SSI](#) as a function of self-reporting social security income, as well as demographic, health, and wealth. This probit is adjusted to target a 4% claiming rate.

The benefit amount is taken from the average monthly benefits found in the 2004 Social Security Annual Statistical Supplement. We assign monthly benefit of \$450 for person aged 51 to 64, and \$350 for persons aged 65 and older.

6.4 Medical costs estimation

In **THEMIS**, a cost module links a person’s current state—demographics, economic status, current health, risk factors, and functional status to 4 types of individual medical spending. **THEMIS** models: total medical spending (medical spending from all payment sources), Medicare spending,⁷ Medicaid spending (medical spending paid by Medicaid), and Out-of-Pocket (**OOP**) spending (medical spending by the respondent). These estimates are based on pooled weighted **OLS** regressions of each type of spending on risk factors, self-reported conditions, and functional status, with spending inflated to constant dollars using the medical component of the Consumer Price Index (**CPI**). We use the 2000-2010 **MEPS** for these regressions for persons not Medicare eligible, and the 2000-2010 **MCBS** for spending for those that are eligible for Medicare. Those eligible for Medicare include people eligible due to age (65+) or due to disability status. Comparisons of prevalences and question wording across these different sources are provided in Tables 1 and 2, respectively.

In the baseline scenario, this spending estimate can be interpreted as the resources consumed by the individual given the manner in which medicine is practiced in the **US** during the post-Part D era (2006-2010). Models are estimated for total, Medicaid, **OOP** spending, and for the Medicare spending. These estimates only use the **MCBS** dataset.

Since Medicare spending has numerous components (Parts A and B are considered here), models are needed to predict enrollment. In 2004, 98.4% of all Medicare enrollees, and 99%+ of aged enrollees, were in Medicare Part A, and thus we assume that all persons eligible for Medicare take Part A. We use the 2007-2010 **MCBS** to model take up of Medicare Part B for both new enrollees into Medicare, as well as current enrollees without Part B. Estimates are based on weighted probit regression on various risk factors, demographic, and economic conditions. The **HRS** starting population for **THEMIS** does not contain information on Medicare enrollment. Therefore another model of Part B enrollment for all persons eligible for Medicare is estimated via a probit, and used in the first year of simulation to assign initial Part B enrollment status. The **MCBS** data overrepresents the portion of eligible adults enrolled in Part B, having a 97% enrollment rate in 2004 instead of the 93.5% rate given by Medicare Trustee’s Report [30]. In addition to this baseline enrollment probit, we apply an elasticity to premiums of -0.10, based on the literature and simulation calibration for actual uptake through 2009 [1, 3]. The premiums are computed using average Part B costs from the previous time step and the means-testing thresholds established by the **ACA**.

Since both the **MEPS** and **MCBS** are known to under-predict medical spending (see, e.g., **Selden and Sing, 2008**, and references therein), we applied adjustment factors to the predicted three types of individual medical spending so that the predicted per-capita spending in **THEMIS** equals the corresponding spending in the National Health Expenditure Accounts (**NHEA**) for age group 55-64 in year 2004 and age 65+ in year 2010, respectively. Table 24 shows how these adjustment factors were determined by using the ratio of expenditures in the **NHEA** to expenditures predicted in **THEMIS**.

Since 2006, the **MCBS** has contained data on Medicare Part D. The data gives the capitated Part D payment and enrollment. When compared to the summary data presented in the **CMS** 2007 Trustee Report [31], the 2006 per capita cost is comparable between the **MCBS** and **CMS**. However, the enrollment is underestimated in the **MCBS**, 53% compared to 64.6% according to **CMS**.

A cross-sectional probit model is estimated using years 2007-2010 to link demographics, economic status, current health, and functional status to Part D enrollment. To account for both the initial underreporting of Part D enrollment in the **MCBS**, as well as the **CMS** prediction that Part D

⁷We estimate annual medical spending paid by specific parts of Medicare (Parts A, B, and D) and sum to get the total Medicare expenditures.

enrollment will rise to 75% by 2012, the constant in the probit model is increased by 0.22 in 2006, to 0.56 in 2012 and beyond.⁸ The per capita Part D cost in the [MCBS](#) matches well with the cost reported from [CMS](#). An [OLS](#) regression using demographics, current health, and functional status is estimated for Part D costs based on capitated payment amounts.

The Part D enrollment and cost models are implemented in the Medical Cost module. The Part D enrollment model is executed conditional on the person being eligible for Medicare, and the cost model is executed conditional on the enrollment model leading to a true result, after the Monte Carlo decision. Otherwise the person has zero Part D cost. The estimated Part D costs are added to Part A and B costs to obtain total Medicare cost, and any medical cost growth assumptions are then applied.

6.5 Taxes

We consider Federal, State and City taxes paid at the household level. We also calculate Social Security taxes and Medicare taxes. [HRS](#) respondents are linked to their spouse in the [HRS](#) simulation. We take program rules from the Organization for Economic Co-operation and Development ([OECD](#)) Taxing Wages Publication for 2004 [[OECD](#)]. Households have basic and personal deductions based on marital status and age (>65). Couples are assumed to file jointly. Social Security benefits are partially taxed. The amount taxable increases with other income from 50% to 85%. Low income elderly have access to a special tax credit and the earned income tax credit is applied for individuals younger than age 65. We calculate state and city taxes for someone living in Detroit, Michigan. The [OECD](#) chose this location because it is generally representative of average state and city taxes paid in the [US](#).

At the state level, there is a basic deduction for each member of the household (\$3,100) and taxable income is taxed at a flat rate of 4%. At the city level, there is a small deduction of \$750 per household member and the remainder is taxed at a rate of 2.55%. There is however a tax credit that decreases with income (20% on the first 100\$ of taxes paid, 10% on the following 50\$ and 5% on the remaining portion).

We calculate taxes paid by the employee for Social Security (Old-Age and Survivors Insurance ([OASI](#)) and [SSDI](#)) and Medicare (Medicaid and Medicare). It does not include the equivalent portion paid by the employer. [OASI](#) taxes of 6.2% are levied on earnings up to \$97,500 (2004 cap) while the Medicare tax (1.45%) is applied to all earnings.

7 Scenarios and robustness

7.1 Obesity reduction scenario

In addition to the status quo scenario, [THEMIS](#) can be used to estimate the effects of numerous possible policy changes. One such set of policy simulations involves changing the trends of risk factors for chronic conditions. This is implemented by altering the incoming cohorts. An useful example is an obesity reduction scenario which rolls back the prevalence of obesity among 50 year-olds to its 1978 level by 2030, where it remains until the end of the scenario, in 2050. This is accomplished by reversing the annual rates of change for Body Mass Index ([BMI](#)) category, hypertension, and diabetes shown in [Table 5](#). As seen in [Table 26](#), this will change the prevalence of obesity among those aged 50+ in 2050. As compared with the status quo estimates ([Table 25](#)),

⁸There is now enough data to estimate these models directly and this effort is underway

THEMIS predicts that by 2050 this will result in a change in the amount of Social Security benefits as well as changing combined Medicare and Medicaid expenditures.

8 Implementation

THEMIS is implemented in multiple parts. Estimation of the transition and cross sectional models is performed in Stata. The incoming cohort model is estimated in Stata using the CMP package [26]. The simulation is implemented in C++ to increase speed.

To match the two year structure of the **HRS** data used to estimate the transition models, **THEMIS** proceeds in two year increments. The end of each two year step is designed to occur on July 1st to allow for easier matching to population forecasts from Social Security. A simulation of **THEMIS** proceeds by first loading a population representative of the age 51+ U.S. population in 2004, generated from **HRS**. In two year increments, **THEMIS** applies the transition models for mortality, health, working, wealth, earnings, and benefit claiming with Monte Carlo decisions to calculate the new states of the population. The population is also adjusted by immigration forecasts from the U.S. Census Department, stratified by race and age. If incoming cohorts are being used, the new 51/52 year olds are added to the population. The number of new 51/52 year-olds added is consistent with estimates from the Census, stratified by race. Once the new states have been determined and new 51/52 year-olds added, the cross sectional models for medical costs, and calculations for government expenditures and revenues are performed. Summary variables are then computed. Computation of medical costs includes the persons that died to account for end of life costs. Other computations, such as Social Security benefits and government tax revenues, are restricted to persons alive at the end of each two year interval. To eliminate uncertainty due to the Monte Carlo decision rules, the simulation is performed multiple times (typically 100), and the mean of each summary variable is calculated across repetitions.

THEMIS takes as inputs assumptions regarding growth in the National Wage Index, **NRA**, real medical cost growth, interest rates, **COLA**, the **CPI**, **SGA**, and deferred retirement credit. The default assumptions are taken from the 2010 **SSI** Intermediate scenario, adjusted for no price increases after the current year. When comparing a single healthcare system innovation (e.g. a new treatment) to the status quo, the future reduction in all-cause mortality and accompanying increases in medical expenditures are normally turned off. Table 27 shows the assumptions for each calendar year and Table 28 shows assumptions for each birth year.

Different simulation scenarios are implemented by changing any of the following components: incoming cohort model, transition models, interventions that adjust the probabilities of specific transition, and changes to assumptions on future economic conditions.

8.1 Intervention module

The intervention module can adjust characteristics of individuals when they are first read into the simulation (initial interventions) or alter transitions within the simulation (transition interventions). At present, initial interventions can act on chronic diseases, **ADL** and **IADL** limitation status, program participation, and some demographic characteristics. Transition interventions can currently act on mortality, chronic diseases, and some program participation variables.

Transition interventions can take several forms. The most commonly used is an adjustment to a transition probability. One can also delay the assignment of a chronic condition or cure an existing chronic condition. Additional flexibility comes from selecting who is eligible for the intervention. Some examples might help to make the interventions concrete:

- Example 1: Delay the enrollment into [OASI](#) by two years. In this scenario claiming of Social Security benefits is transitioned as normal. However, if a person is predicted to claim their benefits, then that status is not immediately assigned, but is instead assigned two years later.
- Example 2: Cure hypertension for those with no other chronic diseases. In this scenario any individual with hypertension (including those who have had hypertension for many years) is cured (hypertension status is set to 0), as long as they do not have other chronic diseases. This example uses the individuals chronic disease status as the eligibility criteria for the intervention.
- Example 3: Reduce the incidence of hypertension for half of men aged 55 to 65 by 10% in the first year of the simulation, gradually increasing the reduction to 20% after 10 years. This example begins to show the flexibility in the intervention module. The eligibility criteria are more complex (half of men in a specific age range are eligible) and the intervention changes over time. Mathematically, the intervention works by acting on the incidence probability, ρ . In the first year of the simulation, the probability is replaced by $(1 - 0.5 * 0.1) \rho = 0.95\rho$. The binary outcome is then assigned based on this new probability. Thus, at the population level, there is a 5% reduction in incidence for men aged 55 to 65, as desired. After 10 years, the probability for this eligible population becomes $(1 - 0.5 * 0.2) \rho = 0.9\rho$.

More elaborate interventions can be programmed by the user.

9 Model development

This section gives some historical background about decisions and developments that led up to the current state of [THEMIS](#).

9.1 Transition model

Section 4.1 describes the current [THEMIS](#) transition model with a focus on discrete absorbing outcomes. In developing this model, it was previously assumed that the time invariant part of the hazard was composed of the effect of observed characteristics x_i and permanent unobserved characteristics specific to outcome m , $\eta_{i,m}$. Consequently, the index was assumed to be of the form $z_{m,j_i} = x_i\beta_m + h_{i,j_i-1,-m}\gamma_m + \eta_{i,m}$ and the latent component of the hazard was modeled as

$$h_{i,j_i,m}^* = x_i\beta_m + h_{i,j_i-1,-m}\gamma_m + \eta_{i,m} + a_{m,j_i} + \varepsilon_{i,j_i,m}, \quad (6)$$

$$m = 1, \dots, M_0, j_i = j_{i0}, \dots, j_{iT_i}, i = 1, \dots, N$$

This is the same as Equation (1), except that Equation (6) uses unobserved characteristics $\eta_{i,m}$ instead of the effects of observed initial conditions $h_{i,j_0,-m}\psi_m$. The unobserved effects $\eta_{i,m}$ are persistent over time and were allowed to be correlated across diseases $m = 1, \dots, M$. We assumed that these effects had a normal distribution with covariance matrix $\mathbf{\Omega}_\eta$.

The parameters $\theta_1 = \left(\{\beta_m, \gamma_m, \varsigma_m\}_{m=1}^M, \text{vech}(\mathbf{\Omega}_\eta) \right)$ could be estimated by maximum simulated likelihood. The joint probability, conditional on the individual frailty is the product of normal univariate probabilities. Similar to the joint probability in Section 4.1, these sequences, conditional on unobserved heterogeneity, are also independent across diseases. The joint probability over all disease-specific sequences is simply the product of those probabilities.

For a given respondent with frailty η_i , the probability of the observed health history is (again, omitting the conditioning on covariates for simplicity)

$$l_i^{-0}(\theta; \eta_i, h_{i,j_{i0}}) = \left[\prod_{m=1}^{M-1} \prod_{j=j_{i1}}^{j_{T_i}} P_{ij,m}(\theta; \eta_i)^{(1-h_{ij-1,m})(1-h_{ij,M})} \right] \times \left[\prod_{j=j_{i1}}^{j_{T_i}} P_{ij,M}(\theta; \eta_i) \right]$$

To obtain the likelihood of the parameters given the observables, it is necessary to integrate out unobserved heterogeneity. The complication is that $h_{i,j_{i0},-m}$, the initial outcomes in each hazard, are not likely to be independent of the common unobserved heterogeneity term which needs to be integrated out. A solution is to model the conditional probability distribution $p(\eta_i | \mathbf{h}_{i,j_{i0}})$ [36]. Implementing this solution amounts to including initial outcomes at baseline (age 50) for each hazard. This is equivalent to writing

$$\begin{aligned} \eta_i &= \Gamma h_{i0} + \alpha_i \\ \alpha_i &\sim N(0, \Omega_\alpha) \end{aligned}$$

Therefore, this allows for permanent differences in outcomes due to differences in baseline outcomes. The likelihood contribution for one respondent's sequence is therefore given by

$$l_i(\theta, \mathbf{h}_{i,j_{i0}}) = \int l_i(\theta; \alpha_i, \mathbf{h}_{i,j_{i0}}) dF(\alpha_i) \quad (7)$$

This model was estimated using maximum simulated likelihood. The likelihood contribution Equation (7) was replaced with a simulated counterpart based on R draws from the distribution of α . The Broyden-Fletcher-Goldfarb-Shanno algorithm was then used to optimize over this simulated likelihood. Convergence of the joint estimator could not be obtained, so the distribution of α_i was assumed to be degenerate. This yielded the simpler estimation problem describe in Section 4.1, where each equation is estimated separately.

9.2 Quality-adjusted life years

9.2.1 Health-related quality-of-life

In general, **HRQoL** measures summarize population health by a single preference-based index measure. A **HRQoL** measure is a suitable measure of a **QALY**. There are several widely-used generic **HRQoL** indexes, each involving a standard descriptive system: a multidimensional measure of health states and a corresponding scoring system to translate the descriptive system into a single index [7]. The scoring system is developed based on a community survey of preference valuation of health states in the descriptive system, using utility valuation methods like time trade-offs or a standard gamble.

9.2.2 HRQoL in the MEPS

Because the health states measures in the **HRS** and **THEMIS** do not match the health states defined in any of the currently available **HRQoL** indexes, we used the **MEPS** to create a crosswalk file for **HRQoL** index calculation. The **MEPS** collects information on health care cost and utilization, demographics, functional status, and medical conditions. **MEPS** initiated a self-administered questionnaire for **SF-12** instrument in year 2000. It also included a self-administered questionnaire for

EQ-5D instrument in years 2001 to 2003. We calculate the EQ-5D and SF-12 scores as the HRQoL measures for THEMIS.

The EQ-5D instrument includes five questions about the extent of problems in mobility, self-care, daily activities, pain, and anxiety/depression. The scoring system for EQ-5D was first developed by Dolan [6] using a UK sample. Later, a scoring system based on a US sample was generated [29]. In the MEPS 2001–2003, there are 25,465 respondents aged 51 and over. Of those respondents, 25,161 gave valid answers for all of the five EQ-5D questions. We calculate EQ-5D scores for these respondents using the scoring algorithm based on a US sample [29]. The distribution of EQ-5D index scores among these respondents is shown in Figure 2.

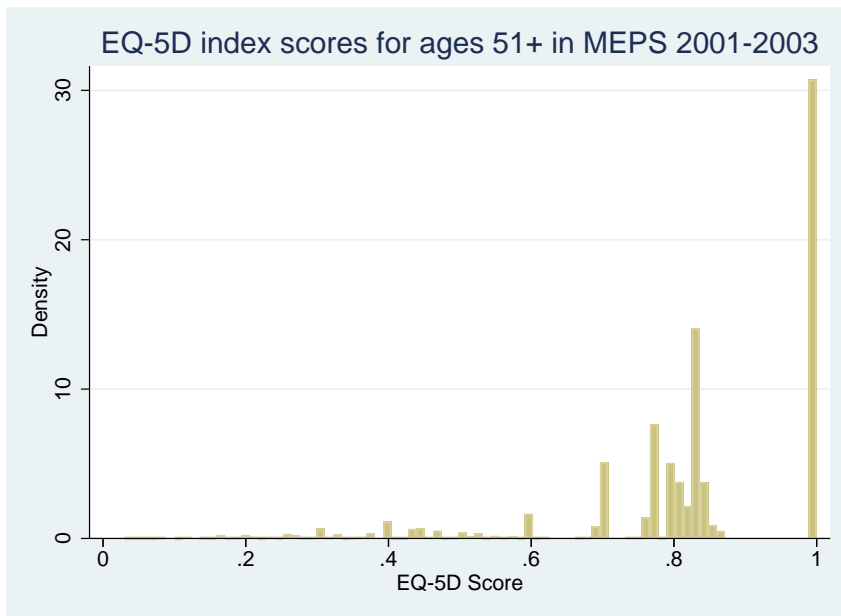


Figure 2: Distribution of EQ-5D index scores for ages 51+ in the 2001–2003 MEPS

The SF-12 instrument is a multipurpose survey consisting of twelve questions to evaluate mental and physical functioning and overall HRQoL. It ranges from 0 to 100, where a zero score indicates the lowest level of health and 100 indicates the highest level of health. SF-12 scoring system was developed by Ware et al. [34] in 1995 and updated in 2002 [35]. MEPS included the first version of SF-12 survey from 2000 to 2002 and the updated SF-12 survey from 2003 onwards. We calculate SF-12 scores for a sample of 96,525 respondents aged 51 and over in MEPS 2003–2012 using the updated scoring algorithm based on Ware et al. [35]. The distribution of SF-12 scores among these respondents is shown in Figure 3.

9.2.3 MEPS-HRS crosswalk development

The functional status measure in THEMIS is based on the HRS. It is a categorical variable including the following mutually exclusive categories: healthy, any IADL limitations (no ADL limitations), 1–2 ADL limitations, and 3 or more ADL limitations. The measures of IADL and ADL limitations in the MEPS are different. The HRS asks questions like “Do you have any difficulty in ...”, while the MEPS asks questions like “Does ...help or supervision in ...” As Table 15 shows, the prevalences of IADL and IADL limitations are relatively similar between the two surveys. As a result, we use these functional status measures comparable across the MEPS and the HRS (the host dataset for THEMIS), in order to compute EQ-5D index scores using functional status in THEMIS. In the

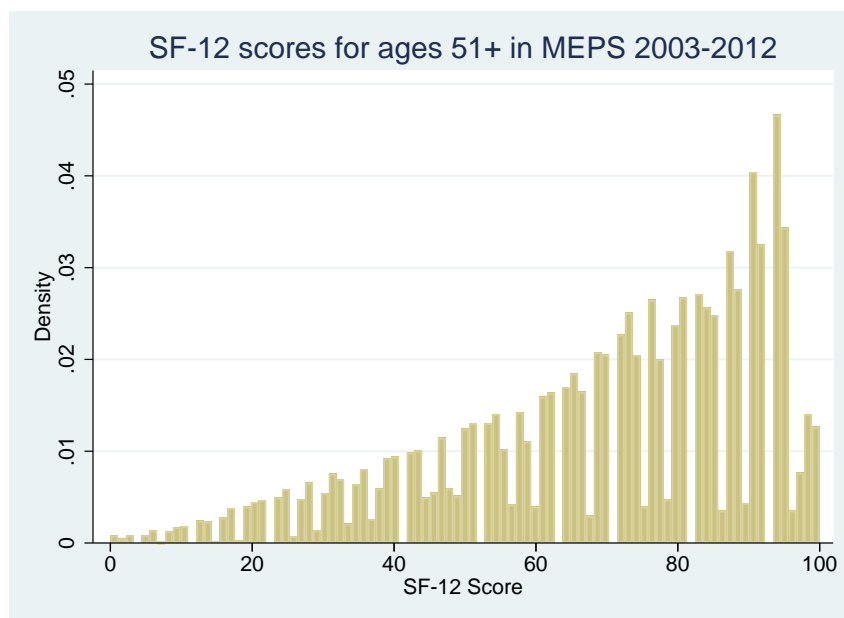


Figure 3: Distribution of SF-12 scores for ages 51+ in the 2003–2012 MEPS

MEPS, IADL limitation indicates receiving help or supervision using the telephone, paying bills, taking medications, preparing light meals, doing laundry, or going shopping. In the HRS, IADL limitation indicates having difficulty in any IADL such as using the phone, managing money, or taking medications.

In addition to functional status limitations, we consider a measure of perceived health status available in both the HRS and the MEPS in the estimation of EQ-5D index scores. Self-reported health is coded as 1-excellent to 5-poor in both surveys. As a part of MEPS-HRS crosswalk we calculate and use the relative value of the mean self-reported health in HRS to that in MEPS by age category.

Using the MEPS 2001–2003 data, we next use OLS regression to model the derived EQ-5D score as a function of seven chronic conditions – which are available in both the HRS and the MEPS, IADL/ADL limitations, and an interaction term of the two measures of functional status. Three different models are considered. Estimation results are presented in Models I–III in Table 16. We also show the estimation results by including variables representing self-reported health in MEPS interacted with age < 75 variable, in addition to the mean value of self-reported health in HRS relative to MEPS interacted with age ≥ 75 variable in Model IV of Table 16. Model V of Table 16 includes additional demographic variables. Model IV was used as the crosswalk described in Section 4.2 to calculate EQ-5D score for individuals aged 51 and over in the HRS data for 1998–2014. Since Model IV over Model V are similar in model fit, we choose Model IV over Model V in order to estimate EQ-5D score according to an individual’s health status variables only.

Following the same MEPS-HRS crosswalk, we develop five models to estimate SF-12 score using the MEPS 2003–2012 data. We use OLS regression to model the derived SF-12 score as a function of IADL/ADL limitations, chronic conditions, self-reported health, and demographic characteristics. These models include mood disorders in addition to the chronic conditions included for EQ-5D score estimation, since MEPS included this health condition in surveys starting in 2003. Estimation results are presented in Models I–V in Table 19. Model IV was used as the crosswalk described in Section 4.3 to calculate SF-12 score for individuals aged 51 and over in the 1998–2014 HRS data.

9.3 Drug expenditures

9.3.1 Drug expenditures - MEPS

Agency for Healthcare Research and Quality produces a file of consolidated annual expenditures for each MEPS respondent in each calendar year. The total drug expenditure variable sums all amounts paid OOP and by third party payers for each prescription purchased in that year. For comparison across years, we convert all amounts to 2016 dollars using the Medical CPI.

9.3.2 Drug expenditures - MCBS

The MCBS produces a Prescribed Medicine Events file at the individual-event level, with cost and utilization of prescribed medicines for the MCBS community population. Collapsing this file to the individual provides an estimate of prescription drug cost for each person. For comparison across years, we convert all amounts to 2016 dollars using the Medical CPI.

There are two caveats to working with these data. The first caveat regards how to handle the "ghost" respondents. "Ghosts" are individuals who enroll in Medicare, but were not asked cost and use questions in the year of their enrollment. For some outcomes, such as medical expenditures, the MCBS makes an effort to impute. For others, such as drug utilization and expenditures, the MCBS does not. We imputed annual drug expenditures for the "ghosts", but for certain age ranges the drug expenditures were not reasonable. This had the biggest effect on the 65/66 year olds, for two reasons. The first is that the 65/66 year olds are more likely to be "ghosts", as 65 is the typical age of enrollment for Medicare. The second is that the 65/66 year olds used for imputation (i.e., the non-"ghosts") are different. To be fully present in the MCBS at age 65 would require enrolling in Medicare before age 65, which happen through a different channel, such as qualifying for Medicare due to receiving disability benefits from the federal government.

The second caveat relates to the filling in zeroes for individuals with no utilization data, but who were enrolled. We assumed that individuals who were not "ghosts" and who did not appear on the Prescribed Medicine Events file had zero prescription expenditures.

9.3.3 Drug expenditures - estimation

Due to the complexities of the age 65/66 population in the MCBS, we chose to estimate the drug expenditure models using the MEPS for individuals aged 51 to 66 and the MCBS for individuals aged 67 and older. Individuals under age 65 receiving Medicare due to disability are estimated separately. Since there are a number of individuals with zero expenditures, we estimate the models in two stages. The first stage is a probit predicting any drug expenditures and the second is an OLS model predicting the amount, conditional on any. Coefficient estimates and marginal effects are shown in the accompanying Excel workbook.

10 Validation

We perform three validation exercises:

1. Cross-validation
2. External validation
3. External corroboration

Cross-validation is a test of the simulation’s internal validity that compares simulated outcomes to actual outcomes, external validation compares model forecasts with actual outcomes from other data sources, and external corroboration compares model forecasts to others’ forecasts.

10.1 Cross-validation

The cross-validation exercise randomly samples half of the [HRS](#) respondent identifiers for use in estimating the transition models. The respondents not used for estimation, but who were present in the [HRS](#) sample in 1998, are then simulated from 1998 through 2012. Demographic, health, and economic outcomes are compared between the simulated ([THEMIS](#)) and actual ([HRS](#)) populations. These results are presented in [Table 9](#) - [Table 14](#) for 2000, 2006, and 2012, with a statistical test of the difference between the average values in the two populations.

Worth noting is how the composition of the population changes in this exercise. In 1998, the sample represents those aged 51 and older. Since we follow a fixed cohort, the age of the population will increase to 65 and older in 2012. This has consequences for some measures in later years where the eligible population shrinks.

On the whole, the cross-validation exercise is reassuring. Comparing simulated outcomes to actual outcomes using a set of transition models estimated on a separate population reveals that the majority of outcomes of interest are not statistically different. In cases where they are, the practical difference is potentially low.

10.2 External validation

The external validation exercise compares [THEMIS](#) full population simulations beginning in 2004 to external sources. Here we focus on per capita benefits received from the [OASI](#), [SSDI](#), and [SSI](#), followed by Medicare and Medicaid.

10.2.1 Benefits from Social Security Administration

Conditional on a simulant receiving benefits, [THEMIS](#) algorithmically assigns benefits for [OASI](#), [SSDI](#), [SSI](#). Here we compare simulation results to [SSA](#) figures.

For the [OASI](#) benefits, we compare to the [SSA](#) December 2012 Monthly Statistical Snapshot. [Table 2](#) of that document indicates that the average [OASI](#) monthly benefit was \$1194. [THEMIS](#) forecasts \$1182 for the average beneficiary for 2012.

For the [SSI](#), we compare to [Table 3](#) of the December 2012 Monthly Statistical Snapshot, focusing on the population aged 65 and older, as that is the only category that is directly comparable. The [SSA](#) reports that the average monthly benefit for December of 2012 was \$417. [THEMIS](#) assigns \$415 to those receiving [SSI](#).

The [SSA](#) does not report [SSDI](#) figures that are directly comparable to [THEMIS](#) forecasts. However, the [SSA](#) reports average [SSDI](#) benefits by age, as well as the number of individuals receiving benefits at each age. This allows us to construct the average benefit for workers 51 and older. Based on this calculation, the average disabled worker aged 51+ received a benefit of \$1212 in December of 2012. Spouses of disabled workers can also receive a benefit ([SSA](#) reports a benefit of \$304 for spouses of disabled workers for all ages). The 2012 [THEMIS](#) forecast for the average [SSDI](#) beneficiary, which includes both workers and their spouses, is \$1102.

10.2.2 Benefits from Medicare and Medicaid

For medical spending, we compare [THEMIS](#) forecasts in 2010 to the [NHEA](#) measures from 2010, the most recent year for which these data are available. [NHEA](#) reports total amounts by age range, which we then convert to per capita measures using the 2010 Census. We focus on the 65-84 and 85 plus age groups, as they are directly comparable to [THEMIS](#) forecasts. We also aggregate the two groups to produce a 65 plus average. [THEMIS](#) is closest to the [NHEA](#) for the Medicare and total medical spending measures. [THEMIS](#) estimates are less accurate for Medicaid spending. These adjustment factors are then used in the simulation results to more closely match the [NHEA](#) numbers.

10.3 External corroboration

Finally, we compare [THEMIS](#) population forecasts to Census forecasts of the U.S. population. Here, we focus on the full [HRS](#) population (aged 51 and older) and those aged 65 and older. For this exercise, we begin the simulation in 2010 and simulate the full population through 2050. Population projections are compared to the 2012 Census projections for years 2012 through 2050. [THEMIS](#) population forecasts are always within two percent of Census forecasts.

11 Baseline forecasts

In this section we present baseline forecasts of [THEMIS](#). The figures show data from the [HRS](#) for the 55+ population from 1998 through 2012 and forecasts from [THEMIS](#) for the 55+ population beginning in 2010.

11.1 Disease prevalence

Figure 4 depicts the six chronic conditions we project for men. And Figure 5 depicts the historic and forecasted values for women.

Figure 6 shows historic and forecasted levels for any [ADL](#) limitations, three or more [ADL](#) limitations, any [IADL](#) limitations, and two or more [IADL](#) limitations for men 55 and older. Figure 7 shows historic and forecasted levels for any [ADL](#) limitations, three or more [ADL](#) limitations, any [IADL](#) limitations, and two or more [IADL](#) limitations for women 55 and older.

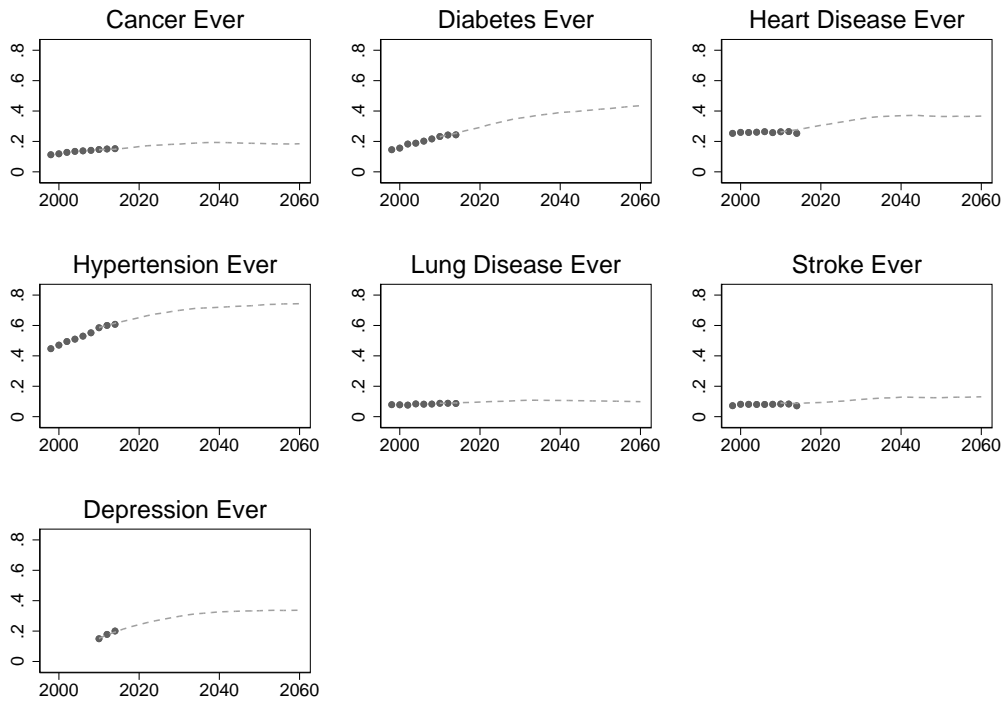


Figure 4: Historic and forecasted chronic disease prevalence for men 55+

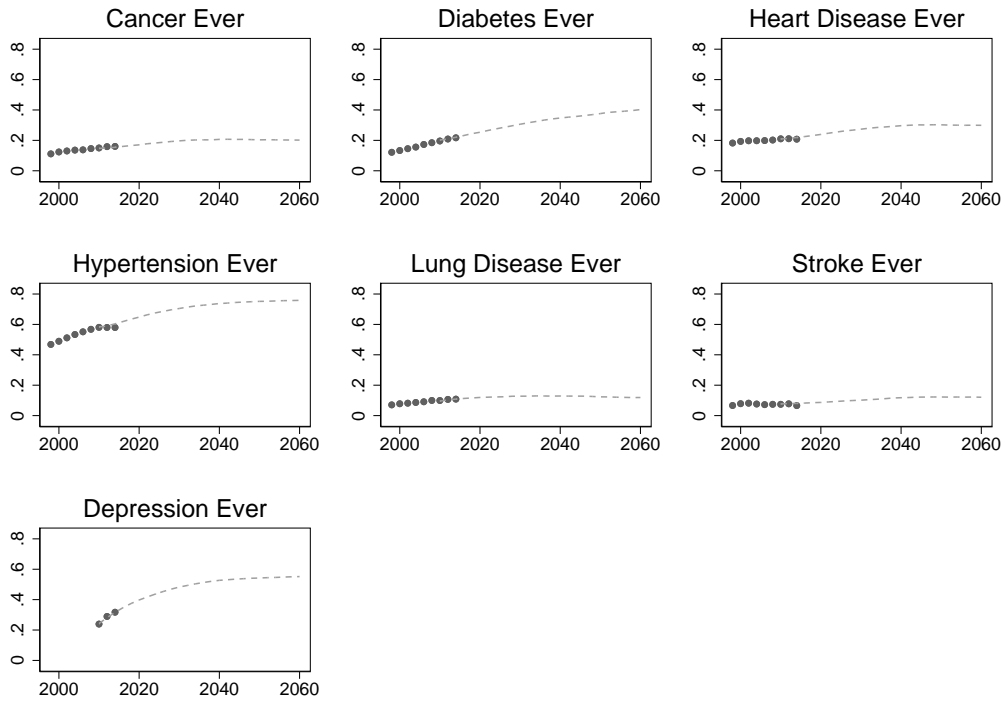


Figure 5: Historic and forecasted chronic disease prevalence for women 55+

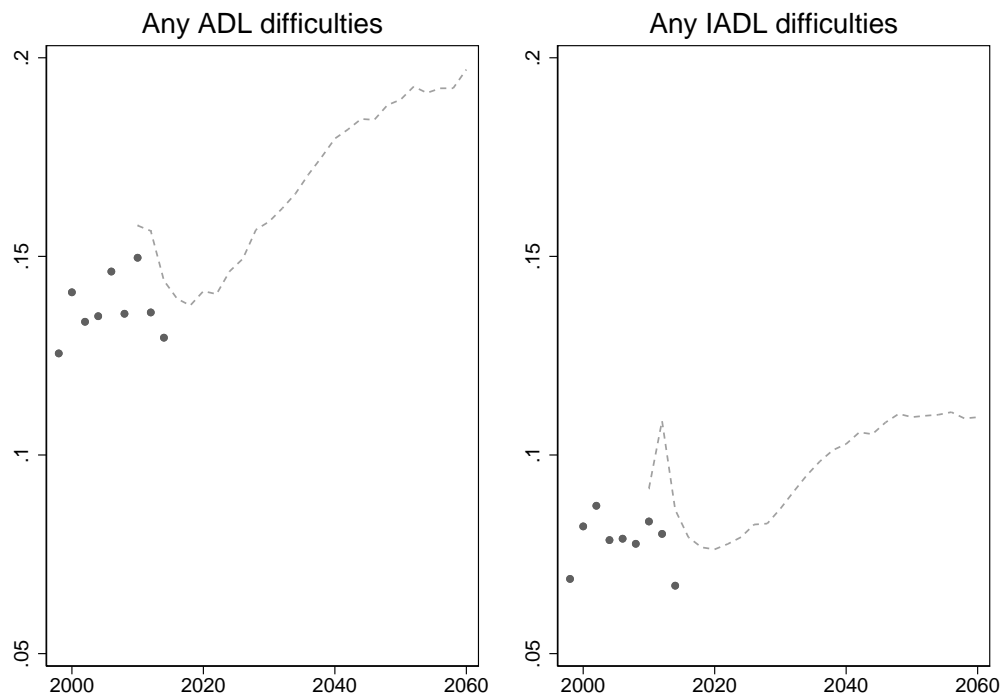


Figure 6: Historic and forecasted [ADL](#) and [IADL](#) prevalence for men 55+

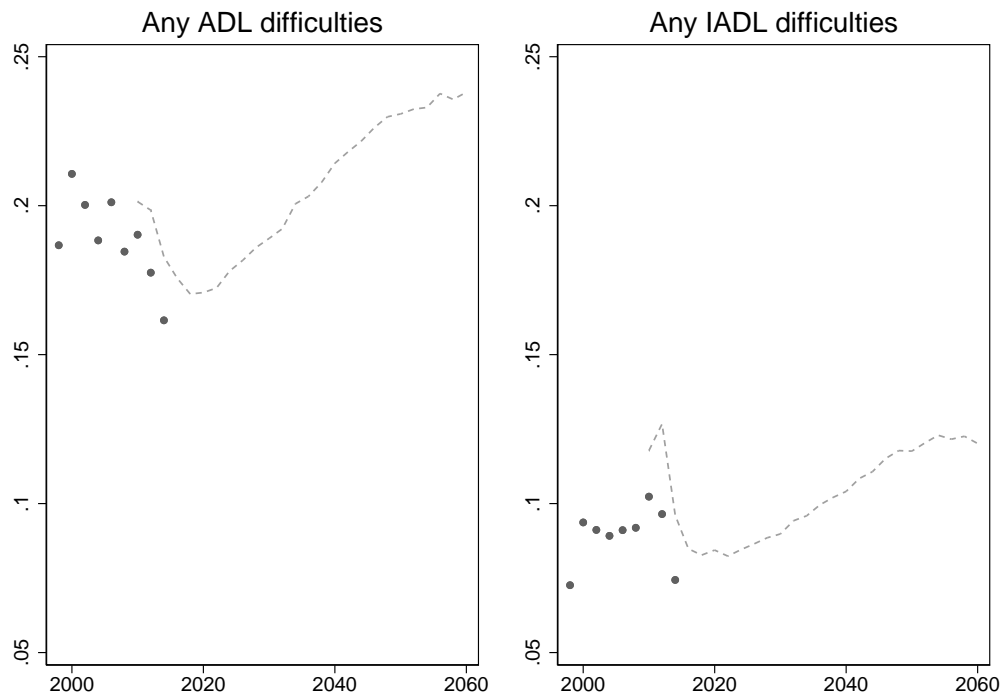


Figure 7: Historic and forecasted [ADL](#) and [IADL](#) prevalence for women 55+

12 Tables

Source (years, ages)	Prevalence %									
	Cancer	Heart Diseases	Stroke	Diabetes	Hypertension	Lung Disease	Depression	Overweight	Obese	
HRS (1991-2008, 55-64)	8%	14%	4%	14%	42%	6%		40%	37%	
NHIS (1997-2010, 55-64)	8%	17%	4%	13%	43%	8%		37%	33%	
MEPS (2000-2010, 55-64)	7%	16%	4%	14%	46%	7%	13%	38%	32%	
HRS (1991-2008, 65+)	16%	29%	10%	17%	54%	10%		38%	26%	
NHIS (1997-2010, 65+)	16%	31%	9%	16%	56%	10%		36%	24%	
MCBS (2000-2010, 65+)	18%	41%	12%	22%	63%	16%	20%	38%	23%	
MEPS (2000-2010, 65+)	12%	33%	11%	19%	63%	9%	11%	38%	24%	

Table 1: Health condition prevalences in survey data

Survey				
HRS	NHIS			
Disease	MEPS	MCBS		
Cancer	Has a doctor ever told you that you have cancer or a malignant tumor, excluding minor skin cancers?	Have you ever been told by a doctor or other health professional that you had cancer or a malignancy of any kind? (WHEN RECODED, SKIN CANCERS WERE EXCLUDED)	List all the conditions that bothered (the person) from (START time) to (END time) CCS codes for the conditions list are 11-21, 24-45	Has a doctor ever told you that you had any (other) kind of cancer malignancy, or tumor other than skin cancer?
Heart Diseases	Has a doctor ever told you that you had a heart attack, coronary heart disease, angina, congestive heart failure, or other heart problems?	Four separate questions were asked about whether ever told by a doctor or other health professional that had: CHD, Angina, MI, other heart problems.	Have you ever been told by a doctor or health professional that you have CHD; Angina; MI; other heart problems	Six separate questions were asked about whether ever told by a doctor that had: Angina or MI; CHD; other heart problems (included four questions)
Stroke	Has a doctor ever told you that you had a stroke?	Have you EVER been told by a doctor or other health professional that you had a stroke?	If Female, add: [Other than during pregnancy,] Have you ever been told by a doctor or health professional that you have a stroke or TIA (transient ischemic attack)	[Since (PREV < SUPP. RD. INT. DATE),] has a doctor (ever) told (you/SP) that (you/he/she) had a stroke, a brain hemorrhage, or a cerebrovascular accident?
Diabetes	Has a doctor ever told you that you have diabetes or high blood sugar?	If Female, add: [Other than during pregnancy,] Have you ever been told by a doctor or health professional that you have diabetes or sugar diabetes?	If Female, add: [Other than during pregnancy,] Have you ever been told by a doctor or health professional that you have diabetes or sugar diabetes?	Has a doctor (ever) told (you/SP) that (you/he/she) had diabetes, high blood sugar, or sugar in (your/his/her) urine? [DO NOT INCLUDE BOORDERLINE PREGNANCY, OR PRE-DIABETIC DIABETES.]
Hypertension	Has a doctor ver told you that you have high blood pressure or hypertension?	Have you EVER been told by a doctor or other health professional that you had Hypertension, also called high blood pressure?	Have you EVER been told by a doctor or other health professional that you had Hypertension, also called high blood pressure?	Has a doctor (ever) told (you/SP) that (you/he/she) (still) (had) (have/has) hypertension, sometimes called high blood pressure?
Lung Disease	Has a doctor ever told you that you have chronic lung disease such a schronic bronchitis or emphysema? [IWER: DO NOT INCLUDE ASTHMA]	Question 1: During the PAST 12 MONTHS, have you ever been told by a doctor or other health professional that you had chronic bronchitis? Question 2: Have you EVER been told by a doctor or other health professional that you had emphysema?	List all the conditions that bothered (the person) from (START time) to (END time) CCS codes for the conditions list are 127, 129-312	Has a doctor (ever) told (you/SP) that (you/he/she) had emphysema, asthma, or COPD? [COPD=CHRONIC OBSTRUCTIVE PULMONARY DISEASE.]
Overweight				
Obese				
				Self-reported body weight and height

Table 2: Survey questions used to determine health conditions

Conditions	Data source	Projection method	Other sources
Diabetes Heart disease Hypertension	National Health Interview Survey 1997-2006	Use synthetic cohort approach to estimate age-specific incidence rate for each condition	There are other forecasts [13, 19] for the trends of diabetes in the U.S population; we compare their forecasts to ours and they are reasonably close
Overweight and obese	Prevalence of overweight and obese for aged 46-56 from year 2001 to 2030, generated by Ruhm upon request	Assume annual rate of change during year 2031-2050 linearly decreases from the 2030 rate to zero in 2050	Ruhm [27]
Ever-smoked and smoking now	Forecast of prevalence of ever-smoked and smoking now for aged 45-54 from year 2005 to 2025, by Levy [16]	For ever-smoked, assume that the prevalence at ages 45-54 in year 2035 (2045) is the same as prevalence at ages 35-44 (25-34) in year 2025. Assume that the annual change in prevalence at ages 45-54 in year 2046-2050 the same as average in 2040-2045. For smoking-now, after year 2025, use the moving average of the past five years	
Any DB from current job		Assume annual relative declining rate for DB entitlement decrease by 2% a year	Historical trends of DB participation rates among all persons by different birth cohorts and by age, by Poterba et al. [23]
Any DC from current job		Assume annual relative increasing rate for DC entitlement increase by 2% a year until 2026 then stays the same after 2026	Forecast of DC participation rates among all persons by different birth cohorts and by age, by Poterba et al. [24]
Population size 50-52 Male Hispanic Non-Hispanic black	Census Bureau 2000-2010 Inter-censal Population Estimates, 2012 National Population Estimates, and 2012 National Population Projections	Projected 2060 - 2080 using linear trend based on 2040-2060	

Table 3: Data sources and methods for projecting future cohort trends

Ratio of future prevalence to 2004 prevalence for 51/52 year olds

Year	Binary outcomes			Ordered outcomes (highest category)		Censored discrete outcomes		
	Hypertension	Heart Disease	Diabetes	BMI Status (BMI \geq 40)	Smoking Status (smoking now)	Any DB Plan	Any DC Plan	Any DC Plan
2010	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2020	1.06	0.95	1.11	1.40	0.82	0.82	1.26	1.26
2030	1.08	0.93	1.14	1.81	0.66	0.67	1.41	1.41
2040	1.10	0.91	1.17	2.18	0.53	0.55	1.41	1.41
2050	1.12	0.90	1.20	2.30	0.41	0.45	1.41	1.41

Table 4: Projected baseline trends for future cohorts

Condition	Prevalence		
	1978	2004	Annual rate of change to get 1978 prevalence by 2030
$30 \leq \text{BMI} < 35$ (kg/m ²)	0.112	0.224	-0.026
$35 \leq \text{BMI} < 40$ (kg/m ²)	0.028	0.058	-0.028
$\text{BMI} \geq 40$ (kg/m ²)	0.014	0.040	-0.040
Hypertension	0.326	0.335	-0.001
Diabetes	0.047	0.094	-0.026
Currently smoking	0.398	0.281	0.013

Table 5: Prevalence of obesity, hypertension, diabetes and current smokers among ages 46-56 in 1978 and 2004. Prevalence in 1978 is based on NHANES II 1976-1980; Prevalence in 2004 is based on NHANES 2003-2004. BMI is calculated using self-reported weight and height.

		Type	At risk	Mean/fraction	
Disease	heart disease	biennial incidence	undiagnosed	0.03	
	hypertension	biennial incidence	undiagnosed	0.04	
	stroke	biennial incidence	undiagnosed	0.01	
	lung disease	biennial incidence	undiagnosed	0.01	
	cancer	biennial incidence	undiagnosed	0.02	
	diabetes	biennial incidence	undiagnosed	0.02	
	depre	biennial incidence	undiagnosed	0.01	
		never smoked	ordered	all	0.41
		ex smoker	ordered	all	0.43
	current smoker	ordered	all	0.16	
	Log BMI	continuous	all	3.35	
Risk Factors	working	prevalence	age < 80	0.49	
	DB pension receipt	biennial incidence	eligible & not receiving	0.02	
LFP & Benefits	SS benefit receipt	biennial incidence	eligible & not receiving	0.11	
	DI benefit receipt	prevalence	eligible & age < 65	0.05	
	Any health insurance	prevalence	age < 65	0.88	
	SSI receipt	prevalence	all	0.03	
	Nursing Home residency	prevalence	all	0.01	
	Death	biennial incidence	all	0.04	
Financial Resources (\$USD 2004)	financial wealth	median	all non-zero wealth	188,055.72	
	earnings	median	all working	18,994.43	
	wealth positive	prevalence	all	0.97	

Table 6: Outcomes in the transition model. Estimation sample is [HRS 1991-2008 waves](#).

	Outcome at time T																				
	Heart disease	hypertension	stroke	Lung disease	diabetes	cancer	disability	mortality	Smoking status	BMI	Any HI	DI Claim	SS Claim	DB Claim	SSI Claim	Nursing Home	Work	Earnings	Nonzero Wealth	Wealth	
Heart disease	✓		✓				✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Blood pressure			✓				✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Stroke			✓				✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Lung disease				✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Diabetes		✓			✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Cancer					✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Disability						✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Claimed DI							✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Claimed SS											✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Claimed DB												✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Claimed SSI												✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Work													✓	✓	✓	✓	✓	✓	✓	✓	✓
Earnings											✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Nonzero wealth											✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Wealth											✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Nursing home stay																✓	✓	✓	✓	✓	✓

Table 7: Restrictions on transition model. ✓ indicates that an outcome at time $T - 1$ is allowed in the transition model for an outcome at time T .

Control variable	Unweighted Statistics			
	Mean	Standard deviation	Minimum	Maximum
Non-Hispanic black	0.141	0.348	0	1
Hispanic	0.0845	0.278	0	1
Less than high school	0.234	0.423	0	1
Some college and above	0.412	0.492	0	1
Male	0.415	0.493	0	1
Ever smoked	0.581	0.493	0	1
Fitted values	1840	1092	0	4273
frq				
Init.of Any DB from current job	0.279	0.448	0	1
fnra3	0.0431	0.203	0	1
fnra4	0.0308	0.173	0	1
fnra5	0.0623	0.242	0	1
Any DC from current job	0.124	0.330	0	1
(IHT of DC wltH in 1000s)/100 if any DC zero otherwise	0.00451	0.0133	0	0.0801

Table 8: Descriptive statistics for exogeneous control variables in 2004 HRS ages 51+ sample used as simulation stock population

Outcome	2000			2006			2012		
	THEMIS mean	HRS mean	<i>p</i>	THEMIS mean	HRS mean	<i>p</i>	THEMIS mean	HRS mean	<i>p</i>
Died	0.058	0.047	0.000	0.070	0.077	0.043	0.088	0.086	0.608
Lives in nursing home	0.017	0.015	0.233	0.029	0.029	0.867	0.041	0.038	0.431

Table 9: Crossvalidation of 1998 cohort: Simulated vs reported mortality and nursing home outcomes in 2000, 2006, and 2012

Outcome	2000			2006			2012		
	THEMIS mean	HRS mean	<i>p</i>	THEMIS mean	HRS mean	<i>p</i>	THEMIS mean	HRS mean	<i>p</i>
Age on July 1st	66.920	66.585	0.010	71.024	70.631	0.003	75.095	74.792	0.026
Black	0.086	0.091	0.182	0.083	0.085	0.562	0.079	0.085	0.289
Hispanic	0.061	0.055	0.051	0.062	0.056	0.095	0.062	0.059	0.516
Male	0.452	0.437	0.016	0.442	0.433	0.223	0.430	0.423	0.400

Table 10: Crossvalidation of 1998 cohort: Simulated vs reported demographic outcomes in 2000, 2006, and 2012

Outcome	2000			2006			2012		
	THEMIS mean	HRS mean	<i>p</i>	THEMIS mean	HRS mean	<i>p</i>	THEMIS mean	HRS mean	<i>p</i>
Alzheimer's							0.034	0.020	0.000
Any ADLs	0.163	0.154	0.066	0.165	0.177	0.036	0.194	0.191	0.660
Any IADLs	0.115	0.067	0.000	0.087	0.088	0.837	0.101	0.111	0.073
Cancer	0.121	0.122	0.908	0.175	0.167	0.127	0.225	0.223	0.793
Normal Cognition	0.823	0.809	0.008	0.803	0.795	0.192	0.763	0.772	0.221
Diabetes	0.150	0.146	0.336	0.208	0.204	0.608	0.257	0.256	0.913
Heart Disease	0.214	0.209	0.386	0.279	0.271	0.183	0.344	0.336	0.327
Hypertension	0.475	0.462	0.042	0.594	0.591	0.763	0.690	0.678	0.127
Lung Disease	0.078	0.074	0.172	0.108	0.093	0.001	0.131	0.114	0.003
Stroke	0.070	0.069	0.937	0.093	0.098	0.286	0.117	0.119	0.766

Table 11: Crossvalidation of 1998 cohort: Simulated vs reported binary health outcomes in 2000, 2006, and 2012

Outcome	2000			2006			2012		
	THEMIS	HRS	<i>p</i>	THEMIS	HRS	<i>p</i>	THEMIS	HRS	<i>p</i>
	mean	mean		mean	mean		mean		
BMI	28.004	27.234	0.000	28.381	27.786	0.000	28.443	27.781	0.000
Current smoker	0.150	0.148	0.620	0.121	0.113	0.073	0.099	0.086	0.009
Ever smoked	0.589	0.592	0.580	0.574	0.582	0.252	0.554	0.567	0.154
TICS-27	16.074	15.687	0.000	16.527	15.268	0.000	16.939	14.801	0.000

Table 12: Crossvalidation of 1998 cohort: Simulated vs reported risk factor outcomes in 2000, 2006, and 2012

Outcome	2000			2006			2012		
	THEMIS	HRS	<i>p</i>	THEMIS	HRS	<i>p</i>	THEMIS	HRS	<i>p</i>
	mean	mean		mean	mean		mean		
Claiming DB pension	0.005	0.015	0.000	0.021	0.015	0.001	0.042	0.026	0.000
Claiming SSDI	0.065	0.041	0.000	0.072	0.086	0.078	0.029	0.129	0.000
Claiming OASI	0.815	0.794	0.021	0.760	0.767	0.528	0.910	0.863	0.000
Claiming SSI	0.028	0.045	0.000	0.018	0.036	0.000	0.013	0.029	0.000
Working for pay	0.434	0.442	0.239	0.337	0.355	0.022	0.262	0.243	0.029

Table 13: Crossvalidation of 1998 cohort: Simulated vs reported binary economic outcomes in 2000, 2006, and 2012

Outcome	2000			2006			2012		
	THEMIS	HRS	<i>p</i>	THEMIS	HRS	<i>p</i>	THEMIS	HRS	<i>p</i>
	mean	mean		mean	mean		mean		
Household wealth (thou.)	450.42	342.63	0	522.62	409.08	0	471.88	346.55	0
Capital income (thou.)	19.548	16.001	0	17.166	12.034	0	13.059	9.6725	1.0e-05
Earnings (thou.)	15.179	16.879	9.0e-05	11.007	12.628	.00046	7.3266	6.7734	.20504

Table 14: Crossvalidation of 1998 cohort: Simulated vs reported continuous economic outcomes in 2000, 2006, and 2012

		MEPS 2001–2003 (ages 51+)					HRS 1998–2014 (ages 51+)		
		ADL limitation					ADL limitation		
		No	Yes	All			No	Yes	All
IADL limitation	No	90.5	0.6	91.1	IADL limitation	No	87.5	2.8	90.3
	Yes	4.7	4.2	8.9		Yes	5.3	4.4	9.7
	All	95.2	4.8	100.0		All	92.8	7.2	100.0

Table 15: Prevalence of **IADL** and **ADL** limitations among ages 51+ in the **MEPS** 2001–2003 and the **HRS** 1998–2014. The **IADL** limitations in **MEPS** are defined as receiving help or supervision using the telephone, paying bills, taking medications, preparing light meals, doing laundry, or going shopping; the **ADL** limitations in the **HRS** are defined as receiving help or supervision with personal care such as bathing, dressing, or getting around the house. The **IADL** limitations in the **HRS** are defined as having any difficulty in at least one of the following activities: using the phone, taking medications, and managing money. The **ADL** limitations in the **HRS** are defined as having any difficulty in at least one of the following activities: bathing, dressing, eating, walking across the room, and getting out of bed.

Covariate	Model I	Model II	Model III	Model IV	Model V
ADL limitation	-0.2368*** (0.000)	-0.2113*** (0.000)	-0.2085*** (0.000)	-0.1552*** (0.000)	-0.1545*** (0.000)
IADL limitation	-0.1710*** (0.000)	-0.1439*** (0.000)	-0.1378*** (0.000)	-0.0870*** (0.000)	-0.0864*** (0.000)
ADL limitation * IADL limitation	0.1086*** (0.000)	0.0979*** (0.000)	0.0917*** (0.000)	0.0548* (0.018)	0.0543* (0.019)
Ever diagnosed with cancer		-0.0160*** (0.001)	-0.0193*** (0.000)	-0.0012 (0.800)	-0.0006 (0.902)
Ever diagnosed with diabetes		-0.0427*** (0.000)	-0.0363*** (0.000)	-0.0088* (0.015)	-0.0108** (0.003)
Ever diagnosed with high blood pressure		-0.0359*** (0.000)	-0.0315*** (0.000)	-0.0157*** (0.000)	-0.0158*** (0.000)
Ever diagnosed with heart disease		-0.0401*** (0.000)	-0.0416*** (0.000)	-0.0151*** (0.000)	-0.0162*** (0.000)
Ever diagnosed with lung disease		-0.0429*** (0.000)	-0.0359*** (0.000)	-0.0131** (0.005)	-0.0108* (0.020)
Ever diagnosed with stroke		-0.0376*** (0.000)	-0.0387*** (0.000)	-0.0198*** (0.001)	-0.0202*** (0.001)
Ever had heart attack		-0.0147 (0.295)	-0.0152 (0.265)	-0.0082 (0.537)	-0.0102 (0.446)
Obese(BMI≥30)			-0.0365*** (0.000)	-0.0284*** (0.000)	-0.0280*** (0.000)
Current smoking			-0.0470*** (0.000)	-0.0316*** (0.000)	-0.0334*** (0.000)
Single			-0.0222*** (0.000)	-0.0141*** (0.000)	-0.0130*** (0.000)
Widowed			-0.0163*** (0.000)	-0.0061 (0.057)	0.0014 (0.662)
Very good self-reported health * age < 75				-0.0375*** (0.000)	-0.0369*** (0.000)
Good self-reported health * age < 75				-0.0773*** (0.000)	-0.0773*** (0.000)
Fair self-reported health * age < 75				-0.1678*** (0.000)	-0.1684*** (0.000)
Poor self-reported health * age < 75				-0.2664*** (0.000)	-0.2667*** (0.000)
Self-reported health HRS/MEPS * age≥75				-0.0426*** (0.000)	-0.0426*** (0.000)
Male					0.0220*** (0.000)
Non-Hispanic black					0.0097** (0.006)
Hispanic					0.0098** (0.008)
Constant	0.8499*** (0.000)	0.8849*** (0.000)	0.9064*** (0.000)	0.9535*** (0.000)	0.9408*** (0.000)
<i>N</i>	25161	24964	24964	24964	24964
<i>R</i> ²	0.14	0.18	0.20	0.31	0.31

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 16: OLS regressions of EQ-5D utility index among ages 51+ in MEPS 2001–2003. p -values in parentheses. Data source: MEPS 2001–2003 (ages 51+). EQ-5D scoring algorithm is based on Shaw et al. [29].

Covariate	EQ-5D
One IADL limitation	-0.0480*** (0.000)
Two or more IADL limitations	-0.0671*** (0.000)
One ADL limitation	-0.0722*** (0.000)
Two ADL limitations	-0.1214*** (0.000)
Three or more ADL limitations	-0.1685*** (0.000)
Ever diagnosed with cancer	-0.0194*** (0.000)
Reports Cognitive Limitations	-0.0250*** (0.000)
Ever diagnosed with mood disorders	-0.0164*** (0.000)
Ever diagnosed with diabetes	-0.0286*** (0.000)
Ever diagnosed with heart disease	-0.0364*** (0.000)
Ever diagnosed with high blood pressure	-0.0331*** (0.000)
Ever diagnosed with lung disease	-0.0423*** (0.000)
Ever diagnosed with stroke	-0.0361*** (0.000)
Ever had heart attack	-0.0296*** (0.000)
Current smoking	-0.0455*** (0.000)
Obese(BMI \geq 30)	-0.0346*** (0.000)
Single	-0.0162*** (0.000)
Widowed	-0.0169*** (0.000)
Constant	0.9109*** (0.000)
<i>N</i>	47532
<i>R</i> ²	0.67
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$	

Table 17: OLS regression of the predicted EQ-5D index score against chronic conditions and THEMIS-type functional status specification. p -values in parentheses. Data source: HRS, 1998–2014. Sample included the age 51 and over respondents. EQ-5D score was predicted using Model IV in Table 16.

Prevalence of chronic conditions

Functional status	Predicted			Prevalence of chronic conditions							
	Estimate	EQ-5D score	SF-12 score	Age	Cancer	Depression	Diabetes	Heart disease	Hypertension	Lung disease	Stroke
Healthy	Mean	0.845	72.7	66.3	0.838	0.794	0.786	0.767	0.410	0.908	0.941
	Sd	0.047	9.1	8.3	0.381	0.399	0.425	0.432	0.482	0.301	0.255
	Std. err	0.001	0.1	0.1	0.004	0.005	0.005	0.005	0.005	0.003	0.003
IADL limitation only - not in nursing home	Mean	0.756	57.2	69.6	0.780	0.518	0.676	0.674	0.343	0.852	0.804
	Sd	0.057	12.0	9.5	0.419	0.500	0.475	0.482	0.462	0.359	0.402
	Std. err	0.003	0.7	0.5	0.023	0.028	0.026	0.027	0.026	0.020	0.022
1 or 2 ADL limitations - not in nursing home	Mean	0.710	51.9	69.1	0.764	0.612	0.659	0.622	0.264	0.812	0.857
	Sd	0.069	12.6	8.7	0.432	0.481	0.488	0.493	0.423	0.406	0.377
	Std. err	0.002	0.4	0.3	0.013	0.015	0.015	0.015	0.013	0.012	0.012
3 or more ADL limitations - not in nursing home	Mean	0.586	35.7	69.3	0.772	0.435	0.588	0.513	0.241	0.716	0.729
	Sd	0.071	14.2	8.9	0.419	0.498	0.492	0.501	0.411	0.446	0.452
	Std. err	0.003	0.7	0.4	0.020	0.024	0.024	0.024	0.020	0.021	0.022
Nursing home residency	Mean	0.597	35.6	74.8	0.709	0.360	0.575	0.550	0.255	0.824	0.551
	Sd	0.099	15.9	6.4	0.466	0.484	0.500	0.502	0.402	0.402	0.498
	Std. err	0.009	1.5	0.6	0.043	0.045	0.047	0.047	0.037	0.037	0.046
All	Mean	0.816	68.3	66.9	0.760	0.690	0.700	0.679	0.355	0.818	0.844
	Sd	0.090	14.7	8.6	0.461	0.479	0.484	0.488	0.454	0.433	0.421
	Std. err	0.001	0.1	0.1	0.004	0.005	0.005	0.005	0.004	0.004	0.004

Table 18: Average predicted EQ-5D and SF-12 scores, age, and prevalence of chronic conditions by functional status for the stock THEMIS simulation sample (ages 51 and over in 2010). EQ-5D and SF-12 scores were predicted according to parameter estimates in Tables 17 and 20, respectively. The predicted score for nursing home residents is reduced by 10% to account for the fact that the estimation sample in Table 17 only includes non-nursing home residents.

Covariate	Model I	Model II	Model III	Model IV	Model V
ADL limitation	-28.4928*** (0.000)	-21.0213*** (0.000)	-21.0835*** (0.000)	-12.6585*** (0.000)	-12.6487*** (0.000)
IADL limitation	-26.6705*** (0.000)	-19.3850*** (0.000)	-18.6184*** (0.000)	-10.8274*** (0.000)	-10.7509*** (0.000)
ADL limitation * IADL limitation	19.4298*** (0.000)	13.9339*** (0.000)	13.6329*** (0.000)	7.5784*** (0.000)	7.6253*** (0.000)
Ever diagnosed with cancer		-3.2281*** (0.000)	-3.8154*** (0.000)	-1.1300*** (0.000)	-1.1594*** (0.000)
Ever diagnosed with diabetes		-6.7449*** (0.000)	-5.8550*** (0.000)	-1.7368*** (0.000)	-1.8299*** (0.000)
Dementia		-6.4585*** (0.000)	-6.9102*** (0.000)	-4.8447*** (0.000)	-4.8723*** (0.000)
Ever diagnosed with mood disorders		-14.1300*** (0.000)	-13.2075*** (0.000)	-9.9237*** (0.000)	-9.5809*** (0.000)
Ever diagnosed with high blood pressure		-5.5310*** (0.000)	-4.6922*** (0.000)	-1.9595*** (0.000)	-2.0670*** (0.000)
Ever diagnosed with heart disease		-5.4312*** (0.000)	-5.4299*** (0.000)	-2.5912*** (0.000)	-2.6795*** (0.000)
Ever diagnosed with lung disease		-9.3538*** (0.000)	-8.3742*** (0.000)	-4.4056*** (0.000)	-4.2549*** (0.000)
Ever diagnosed with stroke		-6.6662*** (0.000)	-6.7124*** (0.000)	-3.4960*** (0.000)	-3.5181*** (0.000)
Ever had heart attack		-2.9308*** (0.000)	-2.9823*** (0.000)	-1.2078** (0.002)	-1.5769*** (0.000)
Obese(BMI \geq 30)			-4.5295*** (0.000)	-2.9845*** (0.000)	-2.9729*** (0.000)
Current smoking			-5.5948*** (0.000)	-2.9834*** (0.000)	-3.2659*** (0.000)
Single			-2.8700*** (0.000)	-1.8710*** (0.000)	-1.7149*** (0.000)
Widowed			-3.5002*** (0.000)	-1.5829*** (0.000)	-0.8653*** (0.000)
Very good self-reported health * age < 75				-5.6922*** (0.000)	-5.6513*** (0.000)
Good self-reported health * age < 75				-14.3179*** (0.000)	-14.3066*** (0.000)
Fair self-reported health * age < 75				-29.1151*** (0.000)	-29.1103*** (0.000)
Poor self-reported health * age < 75				-40.9458*** (0.000)	-40.9245*** (0.000)
Self-reported health HRS/MEPS * age \geq 75				-7.3053*** (0.000)	-7.3049*** (0.000)
Male					2.2081*** (0.000)
Non-Hispanic black					0.3245 (0.080)
Hispanic					0.0027 (0.989)
Constant	71.8606*** (0.000)	82.6846*** (0.000)	85.4412*** (0.000)	92.2559*** (0.000)	91.1238*** (0.000)
<i>N</i>	120421	86294	84039	84039	84039
<i>R</i> ²	0.13	0.30	0.32	0.50	0.50

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 19: OLS regressions of SF-12 utility index among ages 51+ in MEPS 2003–2012. p -values in parentheses. Data source: MEPS 2003–2012 (ages 51+). SF-12 scoring algorithm is based on Ware et al. [35].

Covariate	EQ-5D
One IADL limitation	-6.7534*** (0.000)
Two or more IADL limitations	-7.4537*** (0.000)
One ADL limitation	-9.6937*** (0.000)
Two ADL limitations	-15.0666*** (0.000)
Three or more ADL limitations	-18.9625*** (0.000)
Ever diagnosed with cancer	-4.1654*** (0.000)
Dementia	-8.6224*** (0.000)
Ever diagnosed with mood disorders	-12.6420*** (0.000)
Ever diagnosed with diabetes	-5.1164*** (0.000)
Ever diagnosed with heart disease	-6.2345*** (0.000)
Ever diagnosed with high blood pressure	-5.0670*** (0.000)
Ever diagnosed with lung disease	-9.1758*** (0.000)
Ever diagnosed with stroke	-6.0391*** (0.000)
Ever had heart attack	-4.4132*** (0.000)
Current smoking	-5.6049*** (0.000)
Obese(BMI \geq 30)	-4.0223*** (0.000)
Single	-2.6974*** (0.000)
Widowed	-4.0229*** (0.000)
Constant	84.7445*** (0.000)
<i>N</i>	47532
<i>R</i> ²	0.70
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$	

Table 20: OLS regression of the predicted SF-12 score against chronic conditions and THEMIS-type functional status specification. p -values in parentheses. Data source: HRS, 1998–2014. Sample included the age 51 and over respondents. SF-12 score was predicted using Model IV in Table 19.

		Selection	1992	2010	
Binary	working for pay	all	0.74	0.79	
	non-zero wealth	all	0.97	0.96	
	hypertension	all	0.30	0.41	
	heart disease	all	0.09	0.10	
	diabetes	all	0.07	0.14	
	any health insurance	all	0.86	0.86	
	SRH fair or poor	all	0.18		
Ordered	BMI status	normal	all	0.32	0.22
		overweight	all	0.41	0.35
		$30 \leq \text{BMI} < 35$	all	0.20	0.28
		$35 \leq \text{BMI} < 40$	all	0.04	0.07
		$\text{BMI} \geq 40$	all	0.03	0.08
	Smoking status	never smoked	all	0.36	0.42
		former smoker	all	0.35	0.34
		current smoker	all	0.29	0.24
	Functional status	no ADL	all		
no IADL		all			
Continuous	AIME (nominal \$USD)			2,171.18	
	quarters of coverage		all	101.43	
Censored continuous	earnings	if working	45,578.43	46,823.17	
	wealth	if non-zero	281,087.12	311,874.28	
	DC wealth	if dc plan	18.32	26.97	
Censored discrete	any DB plan	if working	0.43	0.46	
	any DC plan	if working	0.25	0.27	
Censored ordered	Early age eligible DB	<52		0.38	
		52-57		0.13	
		58>		0.36	
	Normal age eligible DB	<57		0.38	
		57-61		0.10	
		62-63		0.16	
		64>		0.10	
Covariates	hispanic	all	0.07	0.11	
	black	all	0.10	0.12	
	male	all	0.46	0.49	
	less high school	all	0.21	0.10	
	college	all	0.41	0.59	
	single	all	0.19	0.27	
	widowed	all	0.04	0.02	
	cancer	all	0.04	0.06	
	lung disease	all	0.04	0.06	
	depre	all		0.24	

Table 21: Initial conditions used for estimation (1992) and simulation (2010)

Covariate	Hypertension		Heart disease		Diabetes		Any health insurance		Self-reported health		Weight status		Smoking status		Functional status (ADL)		Functional status (IADL)		Working		Nonzero wealth		AIME		Quarters worked		IHT(HH wealth)		IHT(eamed income)		Log(DC wealth)		Any DC plan		Any DB plan		Early retirement age		Normal retirement age	
Non-Hispanic black	0.53	0.01	-0.14	0.25	0.45	-0.16	0.49	0.38	-0.12	0.28	0.31	0.19	-0.11	-0.07	-0.93	-20.13	0.12	-0.04	0.01	-0.32	-0.27	0.13	-0.08	0.00	-0.10	-0.07	0.10	0.09	0.10	0.09	0.10	0.09	0.10	0.09	0.10	0.09	0.10	0.09	0.10	0.09
Hispanic	0.10	0.14	-0.09	0.22	0.22	-0.49	0.48	0.10	0.31	0.24	0.46	-0.33	-0.33	-0.37	-15.18	-3.18	-3.22	-0.08	-0.26	-0.31	0.22	-0.04	-0.06	-0.04	-0.15	-0.04	0.10	0.09	0.10	0.09	0.10	0.09	0.10	0.09	0.10	0.09	0.10	0.09	0.10	0.09
Less than high school	-0.05	-0.09	-0.09	-0.09	-0.09	0.18	-0.39	-0.17	-0.12	-0.28	-0.35	-0.35	0.32	0.32	0.81	14.11	5.13	0.09	0.27	0.22	0.22	-0.04	-0.06	-0.04	-0.15	-0.04	0.10	0.09	0.10	0.09	0.10	0.09	0.10	0.09	0.10	0.09	0.10	0.09	0.10	0.09
Some college and above	0.08	0.25	0.07	0.07	0.07	0.03	0.02	0.05	0.43	-0.09	-0.13	-0.13	0.54	0.54	0.02	-2.70	6.98	0.12	0.12	0.15	0.15	-0.06	-0.06	-0.01	-0.01	-0.01	0.01	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Male	0.16	0.05	0.05	0.05	0.05	-0.23	0.24	-0.07	0.33	0.10	0.03	0.07	-1.09	-26.15	0.51	-0.01	0.04	0.01	0.04	0.01	0.04	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Single	0.12	0.10	0.10	0.17	0.17	-0.40	0.30	0.11	0.27	0.01	0.00	0.04	0.04	0.04	-1.04	-18.71	-0.40	-0.02	-0.02	-0.02	-0.02	-0.07	-0.03	-0.04	-0.04	-0.04	0.08	0.09	0.09	0.09	0.08	0.08	0.09	0.09	0.10	0.10	0.10	0.10	0.10	0.10
Widowed	0.32	0.75	0.48	0.48	0.48	-0.05	1.20	0.08	0.61	0.85	0.29	-0.57	-1.17	-17.68	-1.68	-1.68	-1.68	-0.02	-0.13	0.08	0.08	0.09	-0.01	-0.01	-0.10	-0.10	0.08	0.09	0.09	0.09	0.08	0.09	0.09	0.09	0.10	0.10	0.10	0.10	0.10	0.10
Lung disease	0.13	0.19	0.11	0.11	0.11	0.25	0.63	-0.05	0.14	0.36	0.01	0.01	-0.07	0.23	-0.30	-0.30	0.62	-0.05	0.03	-0.09	-0.09	-0.01	-0.01	-0.25	-0.25	-0.01	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	
Cancer	-0.70	-1.54	-1.69	-1.69	-1.69	1.30	-1.21	0.45	0.10	-1.46	-1.35	0.41	2.73	72.82	15.27	15.27	15.27	0.70	-0.59	0.07	0.07	0.30	0.30	0.31	0.31	0.31	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	
constant																																								

Table 22: Parameter estimates for latent model: conditional means and thresholds. Sample is respondents age 50-55 in 1992 HRS wave

	Hypertension	Heart disease	Diabetes	Any health insurance	Self-reported health	Weight status	Smoking status	Functional status (ADL)	Functional status (IADL)	Working	Nonzero wealth	AIME	Quarters worked	IHT(HH wealth)	IHT(earned income)	Log(DC wealth)	Any DC plan	Any DB plan	Early retirement age	Normal retirement age
Hypertension	1.000																			
Heart Disease	0.313	1.000																		
Diabetes	0.304	0.228	1.000																	
Any health insurance	-0.000	0.023	-0.031	1.000																
Self-reported health	0.328	0.490	0.441	-0.100	1.000															
Weight status	0.272	0.100	0.282	-0.011	0.168	1.000														
Smoking status	-0.015	0.067	-0.010	-0.084	0.072	-0.101	1.000													
Functional status (ADL)	0.203	0.307	0.239	-0.054	0.498	0.121	0.033	1.000												
Functional status (IADL)	0.080	0.112	0.108	-0.024	0.151	0.016	-0.015	0.181	1.000											
Working	-0.160	-0.264	-0.241	0.154	-0.415	-0.036	-0.038	-0.361	-0.180	1.000										
Nonzero wealth	-0.180	-0.183	-0.110	0.212	-0.205	0.012	-0.050	-0.176	-0.246	0.368	1.000									
IHT(HH wealth)	-2.020	-2.031	-5.506	7.222	-6.105	-2.269	-4.656	-5.847	-2.209	2.106	0.000	1321.738								
IHT(earned income)	0.273	-0.089	-0.307	3.282	-1.341	0.017	-0.497	-1.142	-0.948	0.000	2.796	57.552	87.128							
Log(DC wealth)	0.016	0.011	-0.007	0.035	-0.011	-0.018	-0.010	0.021	-0.008	0.000	-0.006	2.395	0.918	0.071						
Any DC plan	0.022	0.012	0.064	0.493	-0.063	-0.014	-0.094	-0.065	-0.073	0.000	0.176	3.133	3.458	0.000	1.000					
Any DB plan	0.066	0.023	0.031	0.674	-0.056	0.006	-0.079	-0.053	-0.043	0.000	0.199	2.057	4.563	0.013	0.743	1.000				
Early retirement age	0.111	0.013	-0.076	0.056	0.040	0.055	-0.014	0.010	0.055	0.000	0.007	1.072	-0.054	0.015	-0.198	0.000	1.000			
Normal retirement age	0.100	0.015	-0.085	0.061	0.039	0.046	-0.006	0.011	0.036	0.000	-0.003	0.906	0.179	0.014	-0.188	0.000	0.837	1.000		

Table 23: Parameter estimates for latent model: parameterized covariance matrix. Sample is respondents age 50-55 in 1992 HRS wave

Payment sources	Ages 55-64			Ages 65 and over		
	NHEA 2004 (\$) (A)	THEMIS 2004, unadjusted (\$) (B)	Adjustment factor (A)/(B)	NHEA 2010 (\$) (C)	THEMIS 2010, unadjusted (\$) (D)	Adjustment factor (C)/(D)
Total	7787.00	7479.00	1.04	18424.00	17880.00	1.03
Medicare	706.00	662.00	1.07	10016.00	9956.00	1.01
Medicaid	1026.00	306.00	3.35	2047.00	1050.00	1.95

Table 24: Per capita medical spending by payment source, age group, and year

Year	2010	2030	2050
Population 51+ (Million)	100.09	130.59	149.47
Population 65+ (Million)	45.01	75.66	84.28
Prevalence of selected conditions for ages 51+			
Obesity (BMI \geq 30) (%)	0.39	0.48	0.55
Overweight (25 \leq BMI $<$ 30) (%)	0.37	0.31	0.28
Ever-smoked	0.57	0.49	0.37
Smoking now	0.15	0.10	0.06
Diabetes	0.21	0.32	0.38
Heart disease	0.22	0.30	0.32
Hypertension	0.56	0.68	0.72
Labor participation for ages 51+			
Working (%)	0.44	0.41	0.40
Average earnings if working (\$2010)	48116.79	52582.06	66482.21
Government revenues from ages 51+ (Billion \$2010)			
Federal personal income taxes	439.24	592.43	971.20
Social security payroll taxes	120.36	174.43	265.30
Medicare payroll taxes	32.79	41.78	62.40
Total Revenue	592.39	808.64	1298.90
Government expenditures from ages 51+ (Billion \$2010)			
Old Age and Survivors Insurance benefits (OASI)	665.62	1145.74	1609.73
Disability Insurance benefits (DI)	40.91	48.89	67.78
Supplementary Security Income (SSI)	21.71	27.43	37.58
Medicare costs	473.98	755.64	862.93
Medicaid costs	126.09	215.74	262.71
Medicare + Medicaid	1328.30	2193.43	2840.74
Total medical costs for ages 51+ (Billion \$2010)	1131.41	1729.28	1954.18

Table 25: Simulation results for status quo scenario

	“Obese 1980” Estimates		Relative Change from Status Quo		Absolute Change from Status Quo	
	2030	2050	2030	2050	2030	2050
Year						
Population 51+ (Million)	130.90	152.47	0.00	0.02	0.32	3.00
Population 65+ (Million)	75.87	86.99	0.00	0.03	0.22	2.71
Prevalence of selected conditions for ages 51+						
Obesity (BMI ≥ 30) (%)	0.37	0.33	-0.23	-0.41	-0.11	-0.23
Overweight (25 \leq BMI < 30) (%)	0.35	0.36	0.11	0.28	0.04	0.08
Ever-smoked	0.49	0.38	0.00	0.01	0.00	0.00
Smoking now	0.10	0.06	-0.00	0.01	-0.00	0.00
Diabetes	0.26	0.26	-0.17	-0.31	-0.05	-0.12
Heart disease	0.29	0.30	-0.02	-0.05	-0.01	-0.02
Hypertension	0.66	0.68	-0.03	-0.06	-0.02	-0.04
Labor participation for ages 51+						
Working (%)	0.41	0.40	0.01	0.01	0.00	0.00
Average earnings if working (\$2010)	52,703.47	66,601.55	0.00	0.00	121.41	119.34
Government revenues from ages 51+ (Billion \$2010)						
Federal personal income taxes	602.79	1,003.92	0.02	0.03	10.36	32.72
Social security payroll taxes	176.93	273.04	0.01	0.03	2.51	7.74
Medicare payroll taxes	42.40	64.22	0.01	0.03	0.62	1.82
Total Revenue						
Government expenditures from ages 51+ (Billion \$2010)						
Old Age and Survivors Insurance benefits (OASI)	1,147.27	1,653.74	0.00	0.03	1.53	44.01
Disability Insurance benefits (DI)	42.61	57.05	-0.13	-0.16	-6.28	-10.73
Supplementary Security Income (SSI)	26.68	36.17	-0.03	-0.04	-0.74	-1.41
Medicare costs	743.44	831.74	-0.02	-0.04	-12.20	-31.19
Medicaid costs	210.78	251.85	-0.02	-0.04	-4.95	-10.86
Medicare + Medicaid						
Total medical costs for ages 51+ (Billion \$2010)	1,693.35	1,883.83	-0.02	-0.04	-35.94	-70.35

Table 26: Simulation results for obesity reduction scenario compared to status quo

Calendar year	National Wage Index	Real interest rate on wealth	COLA	Consumer Price Index	Substantial Gainful Activity	Y-o-Y excess real growth in medical costs
2004	35648.55	154.7553	3.606042	188.9	9720	.015
2005	36952.94	157.0766	3.703405	195.3	9960	.0148
2006	38651.41	158.3332	3.855245	201.6	10320	.0147
2007	40405.48	160.0749	3.982468	207.342	10800	.0145
2008	41334.97	163.1163	4.074064	215.303	11280	.0143
2009	42188.9	163.7688	4.31036	214.537	11760	.0141
2010	42907.15	171.4659	4.31036	214.537	12000	.0139
2011	43620.13	173.6949	4.31036	214.537	12000	.0138
2012	44197.64	176.4741	4.31036	214.537	12120	.0136
2013	44678.93	180.533	4.31036	214.537	12480	.0134
2014	45126.4	185.2268	4.31036	214.537	12840	.0133
2015	45737.88	190.7836	4.31036	214.537	13080	.0131
2016	46166.54	196.8887	4.31036	214.537	12699.34	.0129
2017	46633.77	202.5985	4.31036	214.537	12827.86	.0128
2018	47117.93	208.2712	4.31036	214.537	12961.05	.0126
2019	47609.11	214.1028	4.31036	214.537	13096.16	.0124
2020	48107.48	220.0977	4.31036	214.537	13233.25	.0122
2021	48615.77	226.2604	4.31036	214.537	13373.07	.0121
2022	49124.07	232.5957	4.31036	214.537	13512.89	.0119
2023	49625.12	239.1084	4.31036	214.537	13650.72	.0117
2024	50148.08	245.8035	4.31036	214.537	13794.57	.0115
2025	50681.91	252.6859	4.31036	214.537	13941.41	.0114
2026	51221.7	259.7611	4.31036	214.537	14089.9	.0112
2027	51773.64	267.0345	4.31036	214.537	14241.72	.011
2028	52331.86	274.5114	4.31036	214.537	14395.28	.0109
2029	52896.8	282.1978	4.31036	214.537	14550.68	.0107
2030	53472.1	290.0993	4.31036	214.537	14708.93	.0105
2031	54060.84	298.2221	4.31036	214.537	14870.88	.0104
2032	54659.91	306.5723	4.31036	214.537	15035.67	.0101
2033	55273.43	315.1563	4.31036	214.537	15204.43	.01
2034	55892.85	323.9807	4.31036	214.537	15374.82	.0097
2035	56518.25	333.0521	4.31036	214.537	15546.86	.0094
2036	57149.05	342.3776	4.31036	214.537	15720.37	.0091
2037	57790.2	351.9642	4.31036	214.537	15896.74	.0088
2038	58444.8	361.8192	4.31036	214.537	16076.81	.0085
2039	59104.39	371.9501	4.31036	214.537	16258.24	.0082
2040	59771.73	382.3647	4.31036	214.537	16441.81	.0079
2041	60445.75	393.0709	4.31036	214.537	16627.22	.0076
2042	61127.12	404.0769	4.31036	214.537	16814.65	.0073
2043	61816.84	415.3911	4.31036	214.537	17004.37	.007
2044	62511.55	427.022	4.31036	214.537	17195.47	.0067
2045	63211.19	438.9786	4.31036	214.537	17387.93	.0064
2046	63917.93	451.27	4.31036	214.537	17582.33	.0061
2047	64628.21	463.9056	4.31036	214.537	17777.72	.0058
2048	65348.03	476.895	4.31036	214.537	17975.72	.0055
2049	66072.87	490.248	4.31036	214.537	18175.11	.0052
2050	66803.52	503.9749	4.31036	214.537	18376.09	.0049

Table 27: Assumptions for each calendar year

Birth year	Normal Retirement Age	Delayed Retirement Credit
1920	780	.03
1921	780	.03
1922	780	.03
1923	780	.03
1924	780	.03
1925	780	.035
1926	780	.035
1927	780	.04
1928	780	.04
1929	780	.045
1930	780	.045
1931	780	.05
1932	780	.05
1933	780	.055
1934	780	.055
1935	780	.06
1936	780	.06
1937	780	.065
1938	782	.065
1939	784	.07
1940	786	.07
1941	788	.075
1942	790	.075
1943	792	.08
1944	792	.08
1945	792	.08
1946	792	.08
1947	792	.08
1948	792	.08
1949	792	.08
1950	792	.08
1951	792	.08
1952	792	.08
1953	792	.08
1954	792	.08
1955	794	.08
1956	796	.08
1957	798	.08
1958	800	.08
1959	802	.08
1960	804	.08

Table 28: Assumptions for each birth year. In years before 1920, all values are the same as in 1920. In years after 1960, all values are held constant at their 1960 levels.

References

- [1] Atherly, A., Dowd, B. E., and Feldman, R. (2004). The effect of benefits, premiums, and health risk on health plan choice in the medicare program. *Health services research*, 39(4p1):847–864.
- [2] Bhattacharya, J., Shang, B., and Goldman, D. P. (2005). Technological advances in cancer and future spending by the elderly. *Health Affairs*, 24(Suppl 2):W5R53–66.
- [3] Buchmueller, T. (2006). Price and the health plan choices of retirees. *Journal of Health Economics*, 25(1):81–101.
- [4] Council, N. R. (2010). *Improving health care cost projections for the Medicare population: Summary of a workshop*. The National Academies Press.
- [5] Department of Health and Human Services, National Committee on Vital and Health Statistics, Subcommittee on Population Health (2009). Transcript of the February 27, 2009 meeting.
- [6] Dolan, P. (1997). Modeling valuations for euroqol health states. *Medical care*, 35(11):1095–1108.
- [7] Fryback, D. G., Dunham, N. C., Palta, M., Hanmer, J., Buechner, J., Cherepanov, D., Herrington, S., Hays, R. D., Kaplan, R. M., Ganiats, T. G., et al. (2007). Us norms for six generic health-related quality-of-life indexes from the national health measurement study. *Medical care*, 45(12):1162–1170.
- [8] Goldman, D. P., Cutler, D. M., Shang, B., Bhattacharya, J., Joyce, G. F., Lakdawalla, D. N., Panis, C., and Shekelle, P. G. (2005). Consequences of health trends and medical innovation for the future elderly. *Health Affairs*, 24(Suppl 2):W5R5–17.
- [9] Goldman, D. P., Cutler, D. M., Shang, B., and F, J. G. (2006). The value of elderly disease prevention. *Forum for Health Economics & Policy*, 9(2):28.
- [10] Goldman, D. P., Michaud, P. C., Lakdawalla, D. N., Zheng, Y., Gailey, A., and Vaynman, I. (2010). The fiscal consequences of trends in population health. *National Tax Journal*, 63(2):307–330.
- [11] Goldman, D. P., Shekelle, P. G., Bhattacharya, J., Hurd, M., and Joyce, G. F. (2004). Health status and medical treatment of the future elderly. Technical report, DTIC Document.
- [12] Goldman, D. P., Zheng, Y., Girosi, F., Michaud, P. C., Olshansky, S. J., Cutler, D. M., and Row, J. W. (2009). The benefits of risk factor prevention in americans aged 51 years and older. *American Journal of Public Health*, 99(11):2096–2101.
- [13] Honeycutt, A. A., Boyle, J. P., Broglio, K. R., Thompson, T. J., Hoerger, T. J., Geiss, L. S., and Narayan, K. V. (2003). A dynamic markov model for forecasting diabetes prevalence in the united states through 2050. *Health care management science*, 6(3):155–164.
- [14] Lakdawalla, D. N., Goldman, D. P., Michaud, P. C., Sood, N., Lempert, R., Cong, Z., de Vries, H., and Gutierrez, I. (2009). Us pharmaceutical policy in a global marketplace. *Health Affairs*, 28(1):w138–150.

- [15] Lakdawalla, D. N., Goldman, D. P., and Shang, B. (2005). The health and cost consequences of obesity among the future elderly. *Health Affairs*, 24(2):W5R30–41.
- [16] Levy, D. (2006). Trends in smoking rates under different tobacco control policies: results from the SimSmoke tobacco policy simulation model.
- [17] Lubitz, J. (2005). Health, technology, and medical care spending. *Health Affairs*, 24(2):W5R81–5.
- [18] MacKinnon, J. G. and Magee, L. (1990). Transforming the dependent variable in regression models. *International Economic Review*, pages 315–339.
- [19] Mainous III, A., Baker, R., Koopman, R., Saxena, S., Diaz, V., Everett, C., and Majeed, A. (2007). Impact of the population at risk of diabetes on projections of diabetes burden in the united states: an epidemic on the way. *Diabetologia*, 50(5):934–940.
- [20] Michaud, P. C., Goldman, D. P., Lakdawalla, D. N., Zheng, Y., and Gailey, A. H. (2012). The value of medical and pharmaceutical interventions for reducing obesity. *Journal of Health Economics*, 31(4):630–643.
- [OECD] OECD. Taxing wages 2004.
- [22] Office, C. B. (2012). Raising the excise tax on cigarettes: Effects on health and federal budget. Technical report.
- [23] Poterba, J., Venti, S., and Wise, D. A. (2007). The decline of defined benefit retirement plans and asset flows. Technical report, National Bureau of Economic Research.
- [24] Poterba, J. M., Venti, S. F., and Wise, D. A. (2008). New estimates of the future path of 401 (k) assets. In *Tax Policy and the Economy, Volume 22*, pages 43–80. University of Chicago Press.
- [25] Poterba, J. M., Venti, S. F., and Wise, D. A. (2009). The decline of defined benefit retirement plans and asset flows. In *Social Security policy in a changing environment*, pages 333–379. University of Chicago Press.
- [26] Roodman, D. (2011). Fitting fully observed recursive mixed-process models with cmp. *Stata Journal*, 11(2):159–206(48).
- [27] Ruhm, C. J. (2007). Current and future prevalence of obesity and severe obesity in the united states. In *Forum for Health Economics & Policy*, volume 10.
- [28] Selden, T. M. and Sing, M. (2008). Aligning the Medical Expenditure Panel Survey to aggregate us benchmarks. Technical report, Agency for Healthcare Research and Quality.
- [29] Shaw, J. W., Johnson, J. A., and Coons, S. J. (2005). Us valuation of the eq-5d health states: development and testing of the d1 valuation model. *Medical care*, 43(3):203–220.
- [30] THE BOARD OF TRUSTEES, FEDERAL OLD-AGE AND SURVIVORS INSURANCE AND FEDERAL DISABILITY INSURANCE TRUST FUNDS (2009). The 2009 annual report of the board of trustees of the federal old-age and survivors insurance and federal disability insurance trust funds. Technical report, Washington, D.C.

- [31] THE BOARDS OF TRUSTEES, FEDERAL HOSPITAL INSURANCE AND FEDERAL SUPPLEMENTARY MEDICAL INSURANCE TRUST FUNDS (2007). 2007 annual report of the boards of trustees of the federal hospital insurance and federal supplementary medical insurance trust funds. Technical report, Washington, D.C.
- [32] U.S. Census Bureau (2012). U.s. census bureau projections show a slower growing, older, more diverse nation a half century from now. access on Jan 27, 2017.
- [33] US Senate Committee on Health, Education, Labor and Pensions (2008). Examining disease prevention and public health, focusing on transforming the health care system.
- [34] Ware, J. E., Keller, S. D., and Kosinski, M. (1995). Sf-12: How to score the sf-12 physical and mental health summary scales. *Health Institute, New England Medical Center*.
- [35] Ware, J. E., Kosinski, M., Turner-Bowker, D. M., and Gandek, B. (2002). How to score version 2 of the sf-12-v2 health survey. *Boston, MA: Health Assessment Lab*, 22(32.9):32–5.
- [36] Wooldridge, J. M. (2000). A framework for estimating dynamic, unobserved effects panel data models with possible feedback to future explanatory variables. *Economics Letters*, 68(3):245–250.