The Penn Wharton Budget Model's Overlapping Generations Model

Technical Documentation

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Comments are welcome.

The Penn Wharton Budget Model's (PWBM) overlapping generations model (OLG) is a large-scale, stochastic, general equilibrium model that calculates the optimal consumption, leisure, health insurance, and healthcare choices of households of various ages, income groups, health states, and insurance status across their entire lifecycle. Households have access to Social Security (OASI), Medicare, Medicaid, the ACA, employer sponsored health insurance, SNAP and SSI and experience empirically plausible shocks to income and health across the lifecycle. The model features immigration and emigration and detailed income, payroll, corporate income and estate tax modules. Our OLG model is calibrated to match important macroeconomic, healthcare, budget, and demographic moments.

We use the model to analyze changes to federal policies at the aggregate level, such as economic output and federal debt, and changes at the household level, including consumption, labor supply, health status, and health insurance choices. Finally, we use our model to produce a detailed analysis of how proposed changes would affect household's economic well-being.

Keywords: Overlapping generations, lifecycle, healthcare

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1 The Model Economy

The model economy consists of a large number of heterogeneous overlapping-generations households, a government that can credibly commit to a fiscal policy, and a representative firm with constant-returns-to-scale technology.[1] Households face uninsurable idiosyncratic income and health risk, and partially insurable health expenditure risk. They maximize welfare by optimally choosing non-health consumption and leisure, whether to enroll in health insurance, and whether to invest in or forgo medical care.

The government finances outlays for Social Security retirement and survivors benefits (OASI), Medicare, Medicaid, the ACA, SNAP and SSI, together with exogenous outlays that include disability insurance (DI), through income, payroll, corporate income, estate and consumption taxes; states finance their shares of Medicaid and SNAP with a state tax on labor income. The model also allows a wealth tax, which is zero in the baseline. Within this framework, a representative health insurance company operates competitively, generating zero profits. We evaluate the general equilibrium and distributional impacts of policy reforms by computing transition paths between steady states.

Time is discrete and one model period is one year, which is denoted by t.

1.1 Households

1.1.1 Demographics

The economy is populated with households that are ex-ante heterogeneous with respect to the age of the head of household, $j \in J = \{J_B, \ldots, J_D\}$ where J_B is the age of "birth" and J_D is the final year of life in the model; beginning-of-period wealth, $a \in A = [a_{\min}, a_{\max}]$; average historical earnings used to calculate Social Security Old-Age and Survivors Insurance (OASI) benefits, $b \in B = [0, b_{\max}]$; labor productivity, $z \in Z$; health status,

[1] The basic heterogeneous-agent OLG model described in this section is similar to that in Reichling and Nishiyama (2015). The detailed computational procedure to solve those models is described in Nishiyama and Smetters (2014).

$h \in H = \{1, \ldots, h_{\max}\}$; current health needs, $d \in D = \{1, \ldots, d_{\max}\}$ and health insurance status $i \in I$.

An age-j household consists of $\Omega_{a,t}(j)$ adults and $\Omega_{c,t}(j)$ children, and its health status h is measured by the health of the head of household. The probability that an age-j head of household transitions from current health state h to next period's health state h' is given by the Markov transition probability $\pi_h[h'|j, h, d, \iota]$, where ι captures the choice of health expenditures described below. The time-varying period survival probability $\delta_t(j, h)$ depends on current age j and health state h; Section 2.6.4 describes how we calculate it. Households become eligible for Medicare at age $j = J_{Mcare,t}$ and retirement age $j = J_{R,t}$.

The individual state space is defined as the Cartesian product of the sets of idiosyncratic characteristics, $S = J \times A \times B \times Z \times H \times D \times I$. A household's specific state at any point in time is summarized by the vector $s \in S$.

1.1.2 Aggregate Variables and Government Policy

Let ψ_t be the government's policy schedule at the beginning of year t,

$$\begin{aligned}\psi_t = \Big\{ & C_{G,t}, tr_{OASI,t}(\cdot), Med_{Mcare,t}, \pi^{PremSub}_{ACA,t}(\cdot), Med_{Mcaid,t}, SN_t(\cdot), SSI_t(\cdot), \\ & \tau_{I,t}(\cdot), \tau_{P,t}(\cdot), \tau_{C,t}, \tau_{state,t}, \tau_{E,t}(\cdot), \tau_{W,t}(\cdot), \\ & \Big\{\tau^{statutory}_{b,j,t}, \zeta^{ded}_{b,j,t}, \{\phi_{b,j,t,i}\}_{i=0}^{T_d}, \phi^{int}_{b,j,t}, \zeta^{cred}_{b,j,t}, \zeta^{itc}_{b,j,t}\Big\}_{b,j}\Big\}\end{aligned} \tag{1}$$

where $C_{G,t}$ is aggregate exogenous outlays: discretionary spending, Social Security Disability Insurance (DI) benefits, federal retirement, veterans programs, infrastructure, CHIP and other programs, which are dollar totals from the budget baseline deflated by the CPI-U; $tr_{OASI,t}(\cdot)$ is a Social Security Old-Age and Survivors Insurance (OASI) benefit function, which excludes DI benefits because they are part of $C_{G,t}$; $Med_{Mcare,t}$ is the government Medicare benefits function, $Med_{Mcaid,t}$ is the government Medicaid benefit function, $SN_t(\cdot)$ and $SSI_t(\cdot)$ are the SNAP and SSI benefit functions, $\tau_{I,t}(\cdot)$ is an income tax

function, $\tau_{P,t}(\cdot)$ is an OASDI/HI payroll tax function, $\tau_{C,t}$ is a tax function on an exogenously determined share of non-health consumption, $\tau_{state,t}(\cdot)$ is a flat state tax rate on taxable labor income, $\tau_{E,t}(\cdot)$ is an estate tax on bequests net of costs, $\tau_{W,t}(\cdot)$ is a wealth tax on the taxable share of assets (zero in the baseline), and the business tax parameters for each business type b and sector j are the statutory business income tax rate, $\tau_{b,j,t}^{statutory}$, the share of income taken as other deductions, $\zeta_{b,j,t}^{ded}$, the expensing schedule for depreciation allowances, $\phi_{b,j,t,i}$, the deductible share of borrowing costs, $\phi_{b,j,t}^{int}$, the production credit as a share of output, $\zeta_{b,j,t}^{cred}$, and the investment credit as a share of investment, $\zeta_{b,j,t}^{itc}$, all described in Section 1.4. Exogenous outlays, $C_{G,t}$, do not affect a household's well-being, and the proceeds from the consumption tax, $\tau_{C,t}$, are assumed to approximate federal tax revenues other than those from income, payroll, and estate taxes, such as revenues from consumption or VAT taxes, excise taxes, and customs duties.

Let $p_t \in P$ be a vector of all prices in the economy at time t and $p_t^T := \{p_i\}_{i=t}^T$ be the sequence of prices from t to T. Let $\psi_t^T := \{\psi_i\}_{i=t}^T$ be a sequence of government policies from t to T. Let X_t be the distribution of households at time t as defined in Section 1.2. Let $\Psi_t^T = \{p_i, \psi_i, X_i\}_{i=t}^T$.

1.1.3 Utility

Households receive current utility $u(c, l)$ from a numeraire consumption good $c \in C$ and leisure $l \in [0, \Omega_{a,t}(j) l_{\max}] \subset L$, where the maximum amount of available leisure time, $\Omega_{a,t}(j) l_{\max}$, depends on the number of adults, $\Omega_{a,t}(j)$, in the household. Utility is defined as

$$u(c, l) = \frac{\left[c^{\alpha} l^{1-\alpha}\right]^{1-\gamma}}{1-\gamma}. \tag{2}$$

1.1.4 Labor Income

Households have an idiosyncratic Markov ability process z with transition probabilities $\pi_z[z'|z]$ and initial distribution $\pi_z^0(z)$. Household labor productivity is a function $e : J \times H \times Z \to E := [e_{\min}, e_{\max}]$.

Working households aged $j < J_{R,t}$ receive gross wages w_t per working adult so that their total gross income is $y_t^G(j, h, z, l; w_t) = w_t e(j, h, z)(\Omega_{a,t}(j) l_{\max} - l)$.

Retired households receive OASI benefits from the government based on their lifetime average earnings, b, and age: $tr_{OASI,t} : J \times B \to \mathbb{R}^+$.

1.1.5 Health

1.1.5.1 Medical Expenditures

Households face medical expenditures $m_t(j, h, d, i; X)$ that are determined by their age j, the health status of the head of household h, an idiosyncratic expenditure shock $d \in D$, their insurance type i and the distribution of households X. The shock d is i.i.d. and follows a density π_d. We assume that these expenditures can be decomposed as $m_t(j, h, d, i; X) = \nu_t^m(i) \tilde{m}_t(j, h, d; X)$, where $\nu_t^m(i)$ represents the potentially time-varying health care inflation—which varies by insurance type i—and $\tilde{m}_t$ is a time-invariant function of the household's health-relevant state variables and X.

A household's out-of-pocket expenditures $oop_t(m, i)$ are a fraction of its medical expenditures $m_t(j, h, d, i; X)$. A household with $\Omega_{a,t}(j)$ adults and $\Omega_{c,t}(j)$ children has medical expenditures before health care inflation of $\tilde{m}_t(j, h, d; X) = \tilde{m}^H(j, h, d) + (\Omega_{a,t}(j) - 1)\, \tilde{m}^S(j; X) + \Omega_{c,t}(j)\, \tilde{m}^C$, the sum of the head's, each spouse's and each child's expenditures. A person with medical expenditures m in insurance type i pays the fraction $\gamma^{oop}(m, i)$ out of pocket (Section 2.6.2). The household's fraction is the expenditure-weighted average of

its members' fractions,

$$\bar{\gamma}_t^{oop}(j,h,d,i;X) = \frac{1}{\tilde{m}_t(j,h,d;X)}\Big[\gamma^{oop}(\tilde{m}^H,i)\,\tilde{m}^H + (\Omega_{a,t}(j)-1)\,\gamma^{oop}(\tilde{m}^S,i)\,\tilde{m}^S + \Omega_{c,t}(j)\,\gamma^{oop}(\tilde{m}^C,i)\,\tilde{m}^C\Big], \tag{3}$$

where the arguments of $\tilde{m}^H$ and $\tilde{m}^S$ are suppressed. Each member's fraction is evaluated at expenditures before health care inflation, so $\nu_t^m(i)$ raises a household's out-of-pocket expenditures in proportion to its medical expenditures without changing $\bar{\gamma}_t^{oop}$. The fraction is one for the uninsured. If a household chooses not to receive medical treatment (ι=0), total out-of-pocket expenditures are zero. Otherwise,

$$oop_t(m,i) = \bar{\gamma}_t^{oop}(j,h,d,i;X)\,m_t(j,h,d,i;X). \tag{4}$$

The transition probability for health depends on age, current health status, health expenditure choice and idiosyncratic health state: $\pi_h(h'|j,h,d,\iota)$.

1.1.5.2 Health Insurance

Enrollment in public insurance is determined by eligibility: households who qualify for Medicaid or Medicare are automatically enrolled. All other households must decide at time t whether to purchase private health insurance for coverage in $t+1$, prior to the realization of their future health state. For those who opt into coverage, premiums are paid in $t+1$.

There are two ways to qualify for Medicaid: Households with sufficiently low income and wealth qualify categorically; those with sufficiently low income and medical expenses that are greater than a household's available resources qualify medically. There are no insurance premiums associated with Medicaid.

Households of age $J_{Mcare,t}$ and older are automatically enrolled in Medicare Parts A, B, and D, so they are always insured. We calculate Medicare premiums for Parts B and

D following current law and assume that per-enrollee Part B and D premiums grow at the model's trend growth rate plus Medicare excess cost growth rate $\nu_t^m(i = Mcare)$, so they stay a constant share of per-enrollee Medicare spending. Both of those premiums are income-based, so that higher income earners pay higher premiums. We denote an age-j household's Medicare premium by $\pi_{Mcare,t}(y, j)$, which depends on income y and the number of adults per household as determined by the age of the head of household.

There is a single competitive private health insurance market, and working-age households may receive subsidies from their employer or the government. These subsidies depend on the household's realized state in $t + 1$, including their labor income and resulting leisure choice. Total per-household private insurance premiums are defined as $\Omega_{a,t}(j)p_{p,t}(j)$, where $p_{p,t}(j)$ is the per-person premium for an age-j head of household.

A working-age household is offered Employer-Sponsored Insurance (ESI) when ESI exists under the simulated policy, its gross labor income reaches both the cutoff $\underline{y}^{ESI}$ and its own premium $\Omega_{a,t}(j)p_{p,t}(j)$, and it is neither enrolled in Medicare nor categorically eligible for Medicaid. The firm finances a share η^{ESI} of the premium, so the household's portion is $(1 - \eta^{ESI})\Omega_{a,t}(j)p_{p,t}(j)$. The firm's share is cut from the pay of every offered household, whether or not it enrolls. A household that declines the offer therefore forfeits the firm's contribution and the tax exclusion without receiving the contribution as wages.

In our framework, total compensation consists of two components: cash wages and health insurance subsidies. Let o_t^{ESI} equal one if the household is offered ESI, and let $e_t^{ESI} = o_t^{ESI}\,\mathbf{1}_{\{i\neq 0\}}$ equal one if it also enrolls. Paid labor income, $y_t^P(j, h, z, l; w_t)$, equals gross labor income less the firm's share of the premium for every offered household. Only an enrolled household excludes the premium from taxable labor income $y_t^T(j, h, z, l; w_t)$,

up to a cap $\overline{D}^{ESI}$. An offered household that declines is taxed on its paid labor income:

$$y_t^P(j,h,z,l;w_t) = y_t^G(j,h,z,l;w_t) - o_t^{ESI}\,\eta^{ESI}\,\Omega_{a,t}(j)\,p_{p,t}(j) \tag{5}$$

$$y_t^T(j,h,z,l;w_t) = y_t^G(j,h,z,l;w_t) - e_t^{ESI}\,\min\left\{\overline{D}^{ESI},\,\Omega_{a,t}(j)\,p_{p,t}(j)\right\} - \left(o_t^{ESI} - e_t^{ESI}\right)\eta^{ESI}\,\Omega_{a,t}(j)\,p_{p,t}(j) \tag{6}$$

Current law excludes ESI premiums from taxable income without limit, so $\overline{D}^{ESI} = \infty$ in the baseline. Setting $\overline{D}^{ESI} = 0$ removes the exclusion.

Working-age households who do not qualify for ESI may instead receive subsidies through the ACA marketplace. Households may qualify for premium subsidies from the government based on their family size, assets, and income. As under current law, private insurance premiums not purchased under ESI are not tax deductible. We denote the ACA premium subsidies by $\pi_{ACA,t}^{PremSub} : J \times Y^T \times A \to \mathbb{R}^+$.

Households may decide to remain uninsured, in which case they do not have to pay any insurance premiums. The uninsured pay their full medical expenditures out of pocket if they choose to incur the expenses.

Whether enrolled in health insurance or not, households may choose to forgo medical treatment altogether. While forgoing medical treatment saves on out-of-pocket expenditures, it also has downsides: it increases the probability of moving to a worse health state with higher medical expenses, greater mortality probability, and lower labor productivity.

1.1.6 Assets

Households can save one-period, risk-free shares in a mutual fund. The mutual fund, described below, pools all household savings and then invests in domestic government debt and in domestic firms. Each of these investments may earn dividends and capital gains. As described below, the model has both corporate and pass-through firms and their respective dividends may be treated differently for tax purposes. So the household

must keep track of each of the components of the return.

The total return the household receives is

$$r_t = r_t^{corp} + r_t^{pass} + r_t^G + r_t^C \tag{7}$$

where $r_t^{corp}, r_t^{pass}, r_t^G, r_t^C$ are the dividend on corporate capital, the dividend on pass-through capital, the interest payment on one-period government debt, and capital gains from changes in the value of the capital stock, respectively.

1.1.7 Bequests and Inheritances

Households have no bequest motive, but deceased households leave accidental bequests, which are distributed among the currently alive. We assume that a household that dies at the end of the period with planned savings a' enjoys the value of death ζ that does not depend on the household's state or savings (see 1.1.8 below).

The bequest itself incurs some bequest transaction costs, $\Xi(a')$. After those costs, the government collects the rest as a bequest, taxes those bequests with an estate tax and puts the remainder into an inheritance pool, Q_t, to be distributed to the surviving population next period (with interest):

$$Q_t = \int_s (1 - \delta_t(j,h))[\tilde{a}'(s, \Psi_t^{t+J_D-j}) - \tau_{E,t}(\tilde{a}'(s, \Psi_t^{t+J_D-j}))]\, dX_t(\mathbf{s}). \tag{8}$$

where $\tilde{a}'(s, \Psi_t^{t+J_D-j}) = a'(s, \Psi_t^{t+J_D-j}) - \Xi(a'(s, \Psi_t^{t+J_D-j}))$, $\tau_{E,t} : A \to \mathbb{R}^+$ is an estate tax and $\Xi : A \to \mathbb{R}^+$ are transaction costs as described in Feiveson and Sabelhaus (2018b). The transaction costs consist of a fixed deduction, capped at the value of the estate to cover basic expenses such as burial, and a share of the residual estate to cover things such as charitable contributions, estate costs, and other end-of-life costs.

In each period, the government fully distributes the pool Q_t to living households ac-

cording to a function $inh_t : J \times Z \to \mathbb{R}^+$.[2]

For simplicity, we assume that the government collects wealth left by deceased households at the end of year t and then distributes it to households in the following year (with interest) but collects any estate taxes in year t. Because there are no aggregate shocks in the model economy, the government can perfectly predict the sum of accidental bequests (at the end of the year).

The inheritance received by an age-j household at the end of year t is

$$inh_t(j,z) = \omega^q(j,z) \left(\int_s \omega^q(j,z) dX_t(\mathbf{s}) \right)^{-1} Q_t, \tag{9}$$

where $\omega^q(j,z)$ are parameters.

1.1.8 Household Problem

Let $V(s, \Psi_t^{t+J_D-j})$ be the value function of a household of age j at the beginning of year t, where s is the household's state, and $\Psi_t^{t+J_D-j}$ is the sequence of prices, government policies, and household distributions from year t through year $t + J_D - j$, the last year in which the household can be alive (see Section 1.1.2). The household solves

$$\begin{aligned} V(s, \Psi_t^{t+J_D-j}) = \max_{c,l,a',i',\iota} \Big\{ u(c,l) + \tilde{\beta} \Big[\delta_t(j,h) \, \mathbb{E}\big[V(s', \Psi_{t+1}^{t+J_D-j}) \,\big|\, s, \Gamma_h \big] \\ + \big(1 - \delta_t(j,h)\big) \zeta \Big] \Big\}, \qquad j < J_D, \end{aligned} \tag{10}$$

where $\tilde{\beta} \equiv \beta(1+\mu)^{\alpha(1-\gamma)}$ is the growth-adjusted discount factor (Appendix A). At $j = J_D$, the household dies with certainty at the end of the period, so its value is $\max\{u(c,l)\}$. At

[2]While in other settings the way in which bequests are distributed may not matter much, we do not simply distribute bequests lump sum because we want to ensure that households do not receive an unrealistically high minimum consumption floor that would provide insurance against health and health expenditure shocks. Instead, we distribute total bequests by age, based on estimates from the Survey of Consumer Finances.

every age, the household's choices are subject to constraints on the decision variables,

$$c \geq \underline{c}, \qquad 0 \leq l \leq \Omega_{a,t}(j)\, l_{\max}, \qquad a' \geq a'_{\min}(s), \qquad i' \in I, \qquad \iota \in \{0,1\}$$

and the laws of motion for the individual state,

$$\begin{aligned}
s' &= (j+1, a', b', z', h', d', i'), \\
a' &= \frac{\widehat{coh}_t - c + inh_t(j,z)}{1+\mu}, && (11)\\
\widehat{coh}_t &= \max\left\{\underline{c},\ coh_t + SN_t(s,l) - \iota\, oop_t(m(j,h,d,i,X),i)\right\}, && (12)\\
coh_t &= (1+r_t)a + y_t^P + tr_{OASI,t}(j,b,p_{t-j}^t) + SSI_t(s,l) \\
&\quad + \mathbf{1}_{[(i,y,j,a)=ACA]}\, \pi_{ACA,t}^{PremSub}(y_t^T) - T_t(s,c,l) - \pi_t(s,l), && (13)\\
b' &= \mathbf{1}_{\{j<J_{R,t}\}} \frac{1}{j-20}\left[(j-21)\, b\, \frac{w_t}{w_{t-1}} + \min\left(\frac{y_t^T}{\Omega_{a,t}(j)}, \vartheta_{\max}\right)\right] + \mathbf{1}_{\{j\geq J_{R,t}\}} b, && (14)
\end{aligned}$$

where household taxes ($T_t(\cdot)$), health insurance premiums ($\pi_t(\cdot)$) and SNAP benefits ($SN_t(\cdot)$) are

$$\begin{aligned}
T_t(s,c,l) &= \tau_{I,t}\left(y_t^T, \tilde{r}_t a, tr_{OASI,t}(j,b,p_{t-j}^t), \iota\, oop_t, rc_t(j)\right) + \tau_{P,t}(y_t^T) + \tau_{state,t}(y_t^T) \\
&\quad + \tau_{C,t}(\psi_t^C c) + \tau_{W,t}(\psi_t^W a), && (15)\\
\pi_t(s,l) &= \begin{cases} 0 & \text{if } i=0 \text{ or categorically Medicaid-eligible,} \\ \pi_{Mcare,t}(y,j) & \text{if enrolled in Medicare,} \\ (1 - o_t^{ESI}\, \eta^{ESI})\, \Omega_{a,t}(j)\, p_{p,t}(j) & \text{otherwise,} \end{cases} && (16)\\
SN_t(s,l) &= \tilde{SN}_t(s,l) + \max\left\{0,\ \underline{c} - coh_t - \tilde{SN}_t(s,l)\right\}. && (17)
\end{aligned}$$

Here $\tilde{r}_t = (r_t^{corp}, r_t^{pass}, i_t^G, r_t^C)$ is the vector of taxable asset returns, in which government interest enters at the nominal rate; SSI_t denotes Supplemental Security Income transfers;

$\mathbf{1}_{\{\cdot\}}$ is an indicator function equal to one when its condition holds and zero otherwise; and $\vartheta_{\max}$ is the OASDI maximum taxable earnings cap.

Cash on hand coh_t collects the household's assets with their returns and its income and transfers, net of taxes and health insurance premiums. The income tax function $\tau_{I,t}$ applies to taxable labor income y_t^T, taxable asset income $\tilde{r}_t a$ and OASI benefits $tr_{OASI,t}$. The income tax also depends on out-of-pocket medical spending: the household deducts $\iota\, oop_t$ from ordinary taxable income, up to a cap $\overline{oop}_t$. The last argument of $\tau_{I,t}$ is the refundable income tax credit $rc_t(j)$, a fixed amount per household at each age that $\tau_{I,t}$ subtracts from income tax liability. The credit is the intercept of the income tax function: it allows income tax liability to be negative and, because it does not depend on income, leaves marginal tax rates unchanged. The payroll tax $\tau_{P,t}$ and the state tax $\tau_{state,t}$ apply to taxable labor income. For policy experiments, a share of pass-through income can be added to the payroll tax base, but not to the state tax base; that share is zero in the baseline. The wealth tax $\tau_{W,t}$, which applies to the taxable share ψ_t^W of assets, is also zero in the baseline. SNAP benefits SN_t top up the standard benefit $\tilde{SN}_t$ so that $coh_t + SN_t$ reaches the consumption floor $\underline{c}$, and available resources $\widehat{coh}_t$ stay at or above that floor after out-of-pocket medical spending. Savings are divided by $1+\mu$ because individual variables are adjusted for labor-augmenting productivity growth at rate μ. The value of death ζ is set so that households have no incentive to seek an early death by forgoing medical treatment.[3]

Average historical earnings b' evolve recursively as a weighted average of current wage-indexed earnings, $b \cdot w_t / w_{t-1}$, and current OASDI taxable earnings, $\min\{y_t^T/\Omega_{a,t}(j),\ \vartheta_{\max}\}$.[4] They remain constant after retirement.[5]

We divide earnings by the number of adults, $\Omega_{a,t}(j)$, so that the earnings history reflects individual rather than household earnings. Subsection 2.9.1 describes how benefits

[3] See Appendix A for more detail on the importance of ζ and how it is chosen.

[4] For expedience, we keep y_t^T in this notation. The amount that actually enters the earnings history is taxable labor income scaled by η_1^y, the share of labor income subject to the payroll tax.

[5] In the AIME calculation, annual taxable earnings are indexed to the general earnings level in the indexing year (age 60 for most workers), but not in later years. See Social Security Administration (2018). We do not model this change in indexing after age 60.

are computed from individual earnings and rescaled by the average number of adults to approximate expected household benefits.

We collect the household's decision rules and the law of motion for average historical earnings as $\Gamma_h(s, \Psi_t^{t+J_D-j}) \equiv \{c, l, a', i', \iota, b'\}(s, \Psi_t^{t+J_D-j})$.

1.2 The Distribution of Households

We define $X_t(s)$ as the measure of households at state s at time t, with x_t representing the associated density.

1.2.1 Entry and Initial Distribution

Households enter the economy either at "birth" or through immigration. There are time-varying, exogenous entry flows of households, nb_t, at "birth" (age $j = J_B$) and from immigration at any age, $im_t(j)$. There is a time-varying, exogenous exit flow of households due to emigration at any age, $em_t(j)$. Households entering at birth, including immigrants who arrive at age J_B, start with no assets ($a = 0$) and no work history ($b = 0$); immigrants who arrive at older ages are placed in the state space as described below.

Emigration is assumed to occur at the end of period t, while immigration takes place at the beginning of period t. This timing convention follows the Microsim framework, which we replicate in our OLG model to ensure consistency in the evolution of the population.

1.2.1.1 Households entering through birth

We first describe the distribution of native households entering the economy at age $j = J_B \equiv 21$. These agents draw their initial health status h, health expenditure state d and labor ability z from the distributions π_h^0, π_d and π_z^0, respectively. We set the initial distribution over health insurance status (i) at entry according to the following algorithm:

Step 1: For a given Ψ_t^T, we compute the household value and policy functions in Section 1.1.8.

Step 2: For each $(z, h) \in Z \times H$, compute the expected values of having insurance and not having insurance:

$$EV_{0,t}(z,h) = \sum_{d \in D} \pi_d(d) V_t(J_B, 0, 0, z, h, d, 0) \tag{18}$$

$$EV_{1,t}(z,h) = \sum_{d \in D} \pi_d(d) V_t(J_B, 0, 0, z, h, d, 1) \tag{19}$$

Step 3: Define an indicator function $1_i(z,h) = 1$ if $EV_{1,t}(z,h) > EV_{0,t}(z,h)$ and 0 otherwise.

Define a density $\pi_{NB,t}$ by

$$\pi_{NB,t}(a,b,z,h,d,i) = \begin{cases} \pi_z^0(z)\pi_d(d)\pi_h^0(h), & \text{if } a = 0, b = 0 \text{ and } i = 1_i(z,h) \\ 0, & \text{otherwise.} \end{cases} \tag{20}$$

Note that $\pi_{NB,t}$ is time-invariant if we integrate over all insurance choices. In other words,

$$\bar{\pi}_{NB}(a,b,z,h,d) \equiv \sum_{i \in \{0,1\}} \pi_{NB,t}(a,b,z,h,d,i) \tag{21}$$

is time-invariant.

1.2.1.2 Households entering through immigration

Immigrants may enter at any age $j \in J$. Immigrants who arrive at age J_B are part of the entry cohort described above: they are included in the density $\pi_{NB,t}$ in equation (20), and the mass of age-J_B entrants is set to the Microsim population of that age, which includes them. The remainder of this subsection describes immigrants who arrive at age $j > J_B$.

Let $\Pi_t^{\text{immi}}(\cdot \mid j)$ denote the distribution over the state space of immigrant households of age j arriving in period t, with $\pi_t^{\text{immi}}(\cdot \mid j)$ representing the associated density. Unlike entrants at age J_B, these immigrants do not start with $a = 0$ and $b = 0$, and they do not choose insurance according to Steps 1–3. Instead, immigrant households of age j take on

the joint distribution over (a, b, z, h, d, i) of the resident households of the same age:[6]

$$\pi_t^{\text{immi}}(a, b, z, h, d, i \mid j) = \frac{\tilde{X}_t(j, a, b, z, h, d, i)}{\int \tilde{X}_t(j, a, b, z, h, d, i)\, d(a, b, z, h, d, i)}, \qquad j > J_B, \tag{22}$$

where $\tilde{X}_t(j, \cdot)$ is the measure of age-j residents at the start of period t, after survival and emigration from period $t-1$, and before immigrants are added and the population scaling vector is applied. Residents of other ages do not enter the calculation. Equation (22) determines only where immigrants are placed in the state space; the number of immigrants of age j, $im_t(j)$, is taken from the Microsim immigration levels (see Section 1.2.2).[7]

After arrival, immigrant households are not tracked separately. They are added to the household distribution and follow the same law of motion as all other households (see Section 1.2.2).

In contrast to $\bar{\pi}_{NB}$ in equation (21), $\pi_t^{\text{immi}}(\cdot \mid j)$ is not time-invariant: it changes over time with the resident distribution. The measure of immigrants $im_t(j)$ also varies over time (see Section 1.2.2) and is a source of variation in the model. Appendix B describes how immigrants are assigned when the population is divided into groups of workers by skill and nativity.

1.2.2 Law of Motion of Household Distribution

In this section, we describe the evolution of the household distribution over the state space S. Before formally presenting the full law of motion, it is helpful to discuss how emigration and immigration affect the evolution of households.

[6] The code also allows immigrants to enter with zero assets and/or zero earnings history; these alternatives are not used in our simulations.

[7] If $\tilde{X}_t(j, \cdot)$ has no mass, the distribution of age-j residents in period $t-1$ is used instead. If that distribution also has no mass, immigrants enter with $a = 0$ and $b = 0$, with the distribution over (z, h, d) of new entrants of that age, and are split in equal proportion across insurance states, or are assigned $i = 1$ if they are of Medicare age.

1.2.2.1 Survival and Emigration Rates

The distribution of households in period t is given by $x_t(s)$, and the age-specific emigration measures $em_t(j)$ are exogenous. From these, we can compute the **age-specific emigration rate** for each age j as

$$em_t^{\text{rate}}(j) = \frac{em_t(j)}{\hat{x}_t^{\text{microsim}}(j)},$$

where $\hat{x}_t^{\text{microsim}}(j)$ is the total population of age j in period t in Microsim.

We treat emigration as a flat rate applied uniformly across the distribution of each cohort. In particular, we can combine the survival probabilities computed in equation (79) with the emigration rate $em_t^{\text{rate}}(j)$ to obtain the **adjusted survival probability net of emigration**:

$$\tilde{\delta}_t(j,h) = \max\left\{0,\ \delta_t(j,h) - em_t^{\text{rate}}(j)\right\}. \tag{23}$$

The floor at zero ensures that the adjusted survival probability is never negative, which would otherwise imply a negative mass of households.

1.2.2.2 Immigration

Immigration also affects the distribution of households in each period. We combine the distribution of new entrants from immigration, $\pi^{\text{immi}}(s)$, described in section 1.2.1, with the age- and period-specific immigration measure $im_t(j)$: $\pi^{\text{immi}}(s) \cdot im_t(j)$.

1.2.3 Scaling Vector and the Law of Motion of Households

Our OLG model captures substantial heterogeneity, but its demographic accounting is simpler than that of Microsim. For instance, the model does not represent the formation and dissolution of households through marriage and divorce. To keep the model's population by age consistent with Microsim, we apply a scaling adjustment to the population

distribution, $\pi^s_{t+1}(j)$, which absorbs these differences.

Let $\hat{x}^{\text{microsim}}_t(j)$ denote the total population of age j in period t in Microsim, and let $de_t(j)$, $em_t(j)$, and $im_t(j)$ denote the Microsim numbers of deaths, emigrants, and immigrants of age j in period t. The population entering the model at age J_B is set directly to $\hat{x}^{\text{microsim}}_t(J_B)$. For older ages, absent rescaling, the population of age $j+1$ in period $t+1$ would be

$$\hat{x}^{\text{forecast}}_{t+1}(j+1) = \hat{x}^{\text{microsim}}_t(j) - de_t(j) - em_t(j) + im_{t+1}(j+1), \tag{24}$$

that is, this year's population of age j, minus those who die or emigrate, plus next year's immigrants of age $j+1$. Because the model's survival rates are calibrated to the Microsim death rates (Section 2.6.4) and emigration and immigration are taken from Microsim, this is also the population that the model itself produces at age $j+1$ before rescaling. Any difference between $\hat{x}^{\text{forecast}}_{t+1}(j+1)$ and the actual Microsim population $\hat{x}^{\text{microsim}}_{t+1}(j+1)$ comes from demographic changes that the model does not represent, such as marriage and divorce. The *scaling vector* in period $t+1$, $\pi^s_{t+1} : J \to [0, 3]$, corrects for this difference:

$$\pi^s_{t+1}(j) = \frac{\hat{x}^{\text{microsim}}_{t+1}(j)}{\hat{x}^{\text{forecast}}_{t+1}(j)}. \tag{25}$$

The scaling vector depends only on Microsim data, so it is computed once for each year, before the model is solved. As with survival probabilities, it is computed only in the baseline; policy simulations use the baseline scaling vector, even if the policy changes the Microsim population.[8]

The law of motion of the distribution combines the model's demographic transitions, households' decisions, and the scaling vector. The distribution of households across states s' at age $j' = j+1$ in year $t+1$ depends on the distribution over s at age j in year t; on households' decisions about savings, insurance, and medical care, which determine a', b', i', and, through health transitions, h'; and on the arrival of immigrants. For $j =$

[8]The scaling vector is bounded between 0 and 3. In the steady state, next year's population and immigrants in equation (24) are replaced by this year's.

$J_B, \ldots, J_D - 1$,

$$x_{t+1}(s') = \pi^s_{t+1}(j')\Bigg[\int_S \mathbf{1}_{\{a'=a'(),b'=b'(),h'=h'(),i'=i'()\}}\tilde{\delta}_t(j,h)\,\pi_z(z'|z)\;\pi_h(h'|j,\;h,d,\iota())\pi_d(d')\,dX_t(s) + \pi^{\text{immi}}_{t+1}(s' \mid j')\,im_{t+1}(j')\Bigg], \tag{26}$$

where $\mathbf{1}_{\{a'=a'(),b'=b'(),h'=h'(),i'=i'()\}}$ is the indicator function given by the optimal household policy $\Gamma_h(s, \Psi_t^{t+J_D-j})$. Inside the brackets, the integral moves surviving households forward according to their decisions and the transitions for ability, health, and medical expenditures, and the term $\pi^{\text{immi}}_{t+1}(s' \mid j')\,im_{t+1}(j')$ adds immigrants, distributed as in equation (22). The scaling vector $\pi^s_{t+1}(j')$ then rescales the sum so that the population at each age matches Microsim. Households of age J_B enter as described in Section 1.2.1.

1.3 Health Insurers

Insurers in the private insurance market are not allowed to condition policies on observables. However, we do allow for age-based pricing. The insurance market is competitive, so that by the zero-profit condition, individual insurance premiums equal the sum of reimbursable expenses and administrative costs, divided by the number of those who enroll in private insurance. The equation defining the price of private insurance is:

$$p_{p,t}(j, \Psi_t^{t+J_D-j}) = \frac{\omega_j^{HI}}{\sum_j\;\omega_j^{HI}\,\Omega_{a,t}(j)\,\Pi_t(j)(i = private)} \times \frac{\int_S\;\mathbf{1}_{[i=private,\iota=1]}\Big(m_t(j,h,d,i,X_t) - oop_t(m,i)\Big)\;dX_t(s)}{(1-\kappa_{private})} \tag{27}$$

where ι denotes $\iota(s, \Psi_t^{t+J_D-j})$. The weights ω_j^{HI} are age-specific and set such that insurance enrollment closely matches the data. $\Pi_t(j)(i = private)$ is the measure of households of age j at time t enrolled in private health insurance. Administrative expenses associated with providing health insurance are proportional to paid benefits and differ by insurance

type. They are denoted κ_i.

1.4 Firms

There is a representative final goods firm, and a set of intermediate good firms, each representative within their sector. First, we describe the zero-profit final goods firm, which takes the goods from n intermediate goods sectors and combines them into a single output using a Cobb-Douglas production technology. Then we describe the n sectors of intermediate good production, which are produced by both a pass-through entity and a corporation.

1.4.1 Final Goods Firm

The final good—which can be directly consumed by the households or converted into an equal number of new investment goods—is produced competitively by combining the output of the n sectors using a Cobb-Douglas production technology:

$$Y_t = \prod_j Y_{j,t}^{\zeta_j} \;\; s.t. \;\; \sum_j \zeta_j = 1$$

where $Y_{j,t}^{\zeta_j}$ is the total production across both business types in sector j at time t. Normalize the price of the final good to one and let $p_{j,t}$ be the price of good $Y_{j,t}$ $\forall j \in \{1, \ldots, n\}$. Cost minimization implies:

$$p_{j,t} = \zeta_j \frac{Y_t}{Y_{j,t}} \tag{28}$$

1.4.2 The Intermediate Good Firm

1.4.2.1 Business Type

Within each sector of the economy, businesses can be either (a) corporations or (b) pass-through entities. For each sector $j \in \{1, \ldots, n\}$ and each business type $b \in \{corp, pass\}$, the production technology is:

$$Y_{b,j,t} = A_{j,t} K_{b,j,t}^{\alpha_{j,t}^{f}} L_{b,j,t}^{1-\alpha_{j,t}^{f}}$$

Due to constant returns to scale, splitting the "firm" within each sector does not change total production. Note that the TFP ($A_{j,t}$) and the income share to capital ($\alpha_{j,t}^{f}$) are sector-specific, but not specific to the type of business. The share for business type b is parameter $\zeta_{b,j,t}^{income}$ and is used to divide up capital and labor such that

$$K_{b,j,t} = \zeta_{b,j,t}^{income} K_j, \quad L_{b,j,t} = \zeta_{b,j,t}^{income} L_{j,t} \tag{29}$$

where $\sum_b \zeta_{b,j,t}^{income} = 1$, $K_{j,t}$ is total sector capital, and $L_{j,t}$ is total sector labor. It follows that output, $Y_{b,j,t} = \zeta_{b,j,t}^{income} Y_{j,t}$.

We assume that the corporation has an optimization problem, described in the next subsection, and that pass-through firms' capital and labor are determined by the relationships in Equation 29. Note that the pass-through may have different marginal products of capital and labor than the corporations, and the pass-through pays the same wage rate as the corporation.

1.4.2.2 Firm Depreciation Allowances

When making the decision on how to invest, the user cost of capital uses the current net present value of the tax deductions. Nonetheless, the timing of these deductions matters for the rest of the model as government debt "crowds out" productive investment in most

specifications, and therefore the timing of government debt affects the transition path. Therefore, to accurately model the effect of depreciation schedules on the government budget constraint, each firm keeps track of a schedule of depreciation allowances going back T_d years. For a given firm of business type b and sector j, we track the allowance schedule for the next $T_d + 1$ years (typically 40 years, plus the current year).

We define $\phi^{exp}_{b,j,t,i}$, for $i = \{0, \ldots, T_d\}$ at time t and sector $j \in \{1, \ldots, n\}$, as the total value of expensing deductions in n years from t for all historical investments up to period t. For example, $\phi^{exp}_{b,j,t,0}$ is the deduction the corporate firm j takes in period t for all investments made in years up to and *including* year t, whereas $\phi^{exp}_{b,j,t+1,1}$ is the deduction this firm will take in $t + 1$ for all investments made in years up to and *including* year t but *excluding* the investment made in year $t + 1$.

We define every value of $\phi^{exp}_{b,j,t,i}$ for $i = \{0, \ldots, T_d\}$ as follows:

$$\phi^{exp}_{b,j,t,i} = \phi^{exp}_{b,j,t-1,i+1} + \phi_{b,j,t,i}\, I_{b,j,t}\, \frac{pgdp_t}{pgdp_{t+i}}, \qquad I_{b,j,t} = K_{b,j,t+1} - (1 - \delta_{k,j})K_{b,j,t} \tag{30}$$

where $\delta_{k,j}$ is the physical depreciation rate of capital used in sector j, $\phi^{exp}_{b,j,t,T_d+1} = 0$ for all j and t, $\phi^{exp}_{b,j,t,i}$ is the deduction in year $t+i$ for an investment made in year t as defined earlier, and $\phi_{b,j,t,i}$ is the parameter for the portion of investment made i periods ago that should be expensed in period t for a corporate firm in sector j. $I_{b,j,t}$ is investment in year t, as in the firm's problem below. Each value is carried over from the previous year, except for the T_dth year as per the tax code. In the initial steady state, the schedule at T_0 is built as if investment had been constant over the previous T_d years, so every past vintage contributes the same value of investment.

In this case, $\phi_{b,j,t,0}$ is the amount of the expense deduction that the firm gets at time t, while $\phi_{b,j,t,1}$ would be the amount that the firm is allowed to deduct in period $t + 1$ plus whatever amount is allowed to be expensed out of their investments in period $t + 1$.

We treat investment credits as changes to $\phi_{b,j,t,0}$. In this case, the firm gets an extra

deduction reflecting the value of the contemporaneous investment credit.

1.4.2.3 Business Income Subject to Business Taxation

Business taxable income starts with the firm's gross revenue ($p_{j,t}Y_{b,j,t}$) minus the wage bill ($w_t L_{b,j,t}$). From that, we immediately deduct a share of the income for "other" deductions ($\zeta^{ded}_{b,j,t}$) from the firm's revenue net of the wage bill. In addition to those deductions, we allow the firm to deduct accrued investment allowances, $\phi^{exp}_{b,j,t,0}$. Lastly, we allow for an interest rate deduction for business debt $\phi^{int}_{b,j,t}\rho(K_{b,j,t})$, where the term $\rho(K_{b,j,t})$ is the total cost of borrowing.

$$\Pi^{taxable}_{b,j,t} = (1 - \zeta^{ded}_{b,j,t}) \left[p_{j,t}Y_{b,j,t} - w_t L_{b,j,t} \right] - \phi^{exp}_{b,j,t,0} - \left(\frac{K_{b,j,t}}{K_t} \right) C(I_t, K_t) \tag{31}$$

$$- \phi^{int}_{b,j,t} \underbrace{\left[\rho_{b,j,t} B_{b,j,t} + \nu \left(\frac{B_{b,j,t}}{K_{b,j,t}} \right) q_t \nu_2 K_{b,j,t} \right]}_{\rho(K_{b,j,t})} \tag{32}$$

Note that $\zeta^{ded}_{pass,j,t}$ is typically significantly lower than $\zeta^{ded}_{corp,j,t}$, but neither value is zero.

The total business income tax liability is given by

$$T_{b,j,t} = \tau^{statutory}_{b,j,t} \Pi^{taxable}_{b,j,t} - \zeta^{cred}_{b,j,t} p_{j,t} Y_{b,j,t} - \zeta^{itc}_{b,j,t} I_{b,j,t} \tag{33}$$

where $\tau^{statutory}_{b,j,t}$ is the statutory business income tax rate, $\zeta^{cred}_{b,j,t}$ is the share of sector and business output which is a tax credit, and $\zeta^{itc}_{b,j,t}$ is the share of investment that can be claimed as a tax credit. In our baseline, $\tau^{statutory}_{pass,t} = 0$ and $\zeta^{cred}_{pass,j,t} = 0$ for all t. In general, the credit amount, driven by the tax share $\psi_{pass,j,t}$, is determined at the entity level and does not depend on any individual owners' characteristics. Then the credit amount gets apportioned and distributed to the owners along with the pass-through's income.

1.4.2.4 Business Dividends

The net taxes the firm pays are given by:

$$\begin{aligned} T_{b,j,t} = & \tau_{b,j,t}^{statutory}(1-\zeta_{b,j,t}^{ded})\left[p_{j,t}F(K_{b,j,t},L_{b,j,t}) - w_t L_{b,j,t}\right] - \zeta_{b,j,t}^{cred} p_{j,t}F(K_{b,j,t},L_{b,j,t}) \\ & - \tau_{b,j,t}^{statutory}\phi_{b,j,t}^{int}\left[\rho_{b,j,t}B_{b,j,t} + \nu\left(\frac{B_{b,j,t}}{K_{b,j,t}}\right)q_t\nu_2 K_{b,j,t}\right] - \tau_{b,j,t}^{statutory}\phi_{b,j,t,0}^{exp} - \zeta_{b,j,t}^{itc} I_{b,j,t} \\ & - \tau_{b,j,t}^{statutory}\left(\frac{K_{b,j,t}}{K_t}\right)C(I_t,K_t) \end{aligned}$$

The actual money that gets passed back to the mutual fund is equal to:

$$\begin{aligned} \pi_{b,j,t}K_{b,j,t} = & (1-\zeta_{b,j,t}^{other})p_{j,t}Y_{b,j,t} - w_t L_{b,j,t} - \delta_{k,j}K_{b,j,t} - T_{b,j,t} \\ & - \left(\frac{K_{b,j,t}}{K_t}\right)C(I_t,K_t) - \nu\left(\frac{B_{b,j,t}}{K_{b,j,t}}\right)q_t\nu_2 K_{b,j,t} \end{aligned} \tag{34}$$

which are the total revenues minus the total wage bill, minus the economic depreciation, minus the tax bill, minus the fraction of capital adjustment costs, minus the leverage cost. Note that $\pi_{b,j,t}$ is defined as a rate.

It is useful to define the total amount earned by the mutual fund from each business type as:

$$R_{b,t} = \sum_{j=1}^{n} \pi_{b,j,t}K_{b,j,t} \tag{35}$$

1.4.2.5 Price of Capital

Since old and new capital are perfect substitutes in production, their marginal acquisition costs must be identical in equilibrium. We compute the price of existing capital so that the household is indifferent between buying a generic unit of existing capital and a unit of new capital. We assume the output good can be converted into new capital at a one-to-one rate, which makes the price equal to one ($q_t^{new} = 1$).

For new capital, the marginal acquisition cost is 1 unit of the final good less the tax subsidy from investment expensing, ϕ^{npv}, which is the net present value of the tax savings from the deductions on a single unit of new capital (defined below). The price of capital is determined by tax policy alone, since there are no firm-specific capital adjustment costs: each firm takes the aggregate adjustment cost $C(I_t, K_t)$ as given, so it does not enter the firm's investment decision. Therefore, the price of existing capital must be discounted by the net present value of the tax subsidy.

Each firm in sector j and of business type b has its own schedule of deductions for an investment made at time t. The schedule allows for a series of deductions in the year t, in which the investment is made, and the subsequent T_d years. We denote the share of the investment that is deductible in each year $t+n$ by $\phi_{b,j,t,n}$ for $n \in \{0, \ldots, T_d\}$. The net present value of the entire T_d-year stream of deductions for an investment made in time t is defined as:

$$\phi^{npv}_{b,j,t} = \tilde{\tau}_{b,j,t}\phi_{b,j,t,0} + \sum_{n=1}^{T_d}\left(\prod_{i=1}^{n}\frac{1}{1+i^D_{t+i}}\right)\frac{pgdp_t}{pgdp_{t+n}}\tilde{\tau}_{b,j,t+n}\phi_{b,j,t,n} \tag{36}$$

where i^D_t is the nominal effective interest rate on government bonds in period t and $pgdp_t$ is the GDP price index at time t. $\tilde{\tau}_{b,j,t}$ is the tax rate that applies to the income against which the deduction is being taken. For corporations, $\tilde{\tau}_{corp,j,t} = \tau^{statutory}_{b,j,t}$. Pass-through income accrues to all individuals who own assets in the model. For convenience in pricing capital though, we assume that $\tilde{\tau}_{pass,j,t} = \tau^{top}_{pit,t}$, the highest individual marginal tax rate. The fraction of the investment that is deducted in each year of the subsequent T_d years is deflated by both the interest and the inflation rates.

Because the purchaser of new capital in sector j and business type b receives an implicit $\Gamma_{b,j,t} = \zeta^{itc}_{b,j,t} + \phi^{npv}_{b,j,t}$ subsidy from the government while the purchaser of old capital receives no tax subsidy, old capital must also be discounted to make capital purchasers

indifferent between old and new capital.[9]

In the case of corporate investment in sector j, the cost of corporate capital is $1 - \Gamma_{corp,j,t}$. However, because there are n sectors with potentially different tax systems and non-corporate capital also exists, we require a more complex formulation. First, there is no single marginal cost of pass-through capital since pass-through capital income enters into the personal income tax, which is a non-linear function. Then, it becomes necessary to reconcile different costs of corporate and pass-through capital and across sectors. To proceed, we are forced to make additional simplifying assumptions or face having to model a capital trade market. The division of capital between pass-through firms and corporations is fixed exogenously by the time-varying parameters $\zeta^{income}_{pass,j,t}$ and $\zeta^{income}_{corp,j,t}$. Under these assumptions, the cost of existing capital becomes:

$$q_t^{exist} = \sum_{j=1}^{n} \frac{K_{j,t}}{K_t} \left(1 - \zeta^{income}_{corp,j,t}\Gamma_{corp,j,t} - \zeta^{income}_{pass,j,t}\Gamma_{pass,j,t}\right). \tag{37}$$

Note that the price of new capital is $q_t^{new} = 1$, as a unit of new capital costs one unit of the final good. Note that the price of capital should not be confused with the user cost of capital, which is derived later in the corporate firm problem.

[9]This implied market condition only holds so long as the investment is strictly positive. If the economy is disinvesting in aggregate, then the market will not clear at the price of new capital.

1.4.2.6 Corporate Sector Problem - with Interest Rate Deductibility

We define the problem for a representative corporate firm in sector j and $b = corp$ (we use b for notational convenience):

$$
\begin{aligned}
V_{b,j,t}(K_{b,j,t}, \Psi_t^{t+T_d-1}) = \max_{K_{b,j,t+1}, L_{b,j,t}, B_{b,j,t}} & \; p_{j,t} F(K_{b,j,t}, L_{b,j,t}) - w_t L_{b,j,t} \\
& - \tau_{b,j,t}^{statutory} (1 - \zeta_{b,j,t}^{ded}) \left[p_{j,t} F(K_{b,j,t}, L_{b,j,t}) - w_t L_{b,t} \right] + \zeta_{b,j,t}^{cred} p_{j,t} F(K_{b,j,t}, L_{b,j,t}) \\
& + \tau_{b,j,t}^{statutory} \phi_{b,j,t}^{int} \left[\rho_{b,j,t} B_{b,j,t} + \nu \left(\frac{B_{b,j,t}}{K_{b,j,t}} \right) q_t \nu_2 K_{b,j,t} \right] - I_{b,j,t} (1 - \Gamma_{b,j,t}) \\
& - \nu \left(\frac{B_{b,j,t}}{K_{b,j,t}} \right) q_t \nu_2 K_{b,j,t} + \bar{V}_{b,j,t} + \frac{1}{(1 + r_t)} V_{b,j,t}(K_{b,j,t+1} \Psi_{t+1}^{t+T_d}) \\
\text{s.t. } & I_{b,j,t} = K_{b,j,t+1} - (1 - \delta_{k,j}) K_{b,j,t}
\end{aligned}
$$

where q_t is the price of existing capital; $\nu \left(\frac{B_{b,j,t}}{K_{b,j,t}} \right) = \frac{1}{\nu_1} \left(\frac{B_{b,j,t}}{q_t \nu_2 K_{b,j,t}} \right)^{\nu_1}$, where ν_1 is the leverage sensitivity and ν_2 is the scaling of the leverage factor. Note that the price of capital is q_t because that is the average market value of the capital that is collateral; and $\bar{V}_{b,j,t}$ is a sequence of payments taken exogenously[10] by the corporation at time t that do not affect the firm's optimization problem. We assume

$$
\bar{V}_{b,j,t} = \tau_{b,j,t}^{statutory} \phi_{b,j,t-1,1}^{exp} - (1 - \tau_{b,j,t}^{statutory}) \left(\frac{K_{b,j,t}}{K_t} \right) C(I_t, K_t),
$$

where $\phi_{b,j,t-1,1}^{exp}$ corresponds to the total investment expensing allowances for all investments made up until $t-1$ and paid in period t (formally defined later), and $C(I_t, K_t)$ is the (tax-deductible) convex capital adjustment cost function for the economy whereby each firm pays a fraction of such cost proportional to its size in terms of capital. For the total cost of gross investment I_t, given a current aggregate capital stock K_t:

$$
C(I_t, K_t) = \eta \left(\frac{I_t}{K_t} \right) I_t
$$

[10] This is by assumption.

$\zeta^{itc}_{b,j,t}$ is the initial investment credit.

The cost of investment is symmetric around zero because we assume that the depreciation schedule applies equally to investment and disinvestment. Firms make decisions treating existing capital the same regardless of whether it is being bought or sold. In the case of disinvestment, the firm may owe additional taxes in the future as these are treated as negative deductions. Let $\Gamma^{f}_{b,j} : K \times \gtrless^{T_d+1} \to \mathbb{R}^2_+$ be the optimal policy function for firms.

1.4.2.7 Wages and the FONC with Respect to Labor

The first-order condition with respect to labor sets the wage equal to the marginal product of labor, net of business taxes, deductions, and credits (note that we substitute in Equation (28) to get this relationship):

$$w_t = \Phi^{W}_{b,j,t} \zeta_j \frac{Y_t}{L_{j,t}} \quad \forall j \tag{38}$$

where

$$\Phi^{W}_{b,j,t} = \frac{[1 - \tau^{statutory}_{b,j,t}(1 - \zeta^{ded}_{b,j,t}) + \zeta^{cred}_{b,j,t}](1 - \alpha^{f}_{j,t})}{1 - \tau^{statutory}_{b,j,t}(1 - \zeta^{ded}_{b,j,t})}. \tag{39}$$

The factor $\Phi^{W}_{b,j,t}$ captures the effect of business taxes, deductions, and credits on the cost of labor. Without them, $\Phi^{W}_{b,j,t} = 1 - \alpha^{f}_{j,t}$, and the wage equals the marginal product of labor, $(1 - \alpha^{f}_{j,t})\, \zeta_j Y_t / L_{j,t}$.

The firm subsidizes health insurance premiums for employees that qualify, so that gross and paid labor income differ.

$$\begin{aligned} w_t\, L_t &= \sum_{j=21}^{J_{R,t}-1} \int_{A\times B\times E\times H\times I} y^{G}_t(j,h,z,l,w_t)\, dX_t(s), \\ &= \sum_{j=21}^{J_{R,t}-1} \int_{A\times B\times E\times H\times I} \left(y^{P}_t(j,h,z,l,\iota,w_t) + o^{ESI}_t\, \eta^{ESI}\, \Omega_{a,t}(j)\, p_{p,t}(j) \right) dX_t(s) \end{aligned}$$

1.4.2.8 Borrowing and FONC with Respect to Debt

The first-order condition with respect to debt is:

$$\frac{V_{b,j,t}}{B_{b,j,t}} : 0 = \tau_{b,j,t}^{statutory} \phi_{b,j,t}^{int} \left[\rho_{b,j,t} + \frac{B_{b,j,t}^{\nu_1 - 1}}{(q_t \nu_2 K_{b,j,t})^{\nu_1}} q_t \nu_2 K_{b,j,t} \right] - \frac{B_{b,j,t}^{\nu_1 - 1}}{(q_t \nu_2 K_{b,j,t})^{\nu_1}} q_t \nu_2 K_{b,j,t}$$

Rearranging, we get a level of debt that is optimal for a specific level of firm capital.

$$B_{b,j,t} = \left(\frac{\tau_{b,j,t}^{statutory} \phi_{b,j,t}^{int} \rho_{b,j,t}}{1 - \tau_{b,j,t}^{statutory} \phi_{b,j,t}^{int}} \right)^{\frac{1}{\nu_1 - 1}} q_t \nu_2 K_{b,j,t} \tag{40}$$

1.4.2.9 User Cost of Capital

The first-order condition with respect to capital leads to the following relationship:

$$\begin{aligned} \frac{dV_{b,j,t}}{dK_{b,j,t+1}} : 0 = & -\frac{(1 - \Gamma_{b,j,t})}{(1+r)^{t-1}} + \frac{1}{(1+r)^t} \Big\{ p_{j,t+1} F_{b,j,t+1}^K - \tau_{b,j,t+1}^{statutory} (1 - \zeta_{b,j,t+1}^{ded}) p_{j,t+1} F_{b,j,t+1}^K \\ & + \zeta_{b,j,t+1}^{cred} p_{j,t+1} F_{b,j,t+1}^K + \left(\tau_{b,j,t+1}^{statutory} \phi_{b,j,t+1}^{int} - 1 \right) \frac{1 - \nu_1}{\nu_1} \left(\frac{B_{b,j,t+1}}{q_{t+1} \nu_2} \right)^{\nu_1} K_{b,j,t+1}^{-\nu_1} q_{t+1} \nu_2 \\ & + (1 - \delta_{k,j})(1 - \Gamma_{b,j,t+1}) \Big\} \end{aligned}$$

Rearranging the terms, we are able to get a discrete-time definition of the user cost of capital:

$$\begin{aligned} F_{b,j,t+1}^K &= \frac{(1 - \Gamma_{b,j,t})(1+r) + \left(q_{t+1} \nu_2 \frac{1 - \nu_1}{\nu_1} \right) \frac{\left(\tau_{b,j,t+1}^{statutory} \phi_{b,j,t+1}^{int} \rho_{b,j,t+1} \right)^{\frac{\nu_1}{\nu_1 - 1}}}{\left(1 - \tau_{b,j,t+1}^{statutory} \phi_{b,j,t+1}^{int} \right)^{\frac{1}{\nu_1}}} - (1 - \delta_{k,j})(1 - \Gamma_{b,j,t+1})}{p_{j,t+1} \left[1 - \tau_{b,j,t+1}^{statutory} (1 - \zeta_{b,j,t+1}^{ded}) + \zeta_{b,j,t+1}^{cred} \right]} \\ &= \frac{\Phi_{b,j,t+1}^R}{p_{j,t+1}} \end{aligned} \tag{41}$$

$$\text{where } \Phi^{R}_{b,j,t+1} \equiv \frac{(1-\Gamma_{b,j,t})(1+r)+\left(q_{t+1}\nu_2\frac{1-\nu_1}{\nu_1}\right)\frac{\left(\tau^{statutory}_{b,j,t+1}\phi^{int}_{b,j,t+1}\rho_{b,j,t+1}\right)^{\frac{\nu_1}{\nu_1-1}}}{\left(1-\tau^{statutory}_{b,j,t+1}\phi^{int}_{b,j,t+1}\right)^{\frac{1}{\nu_1}}}-(1-\delta_{k,j})(1-\Gamma_{b,j,t+1})}{\left[1-\tau^{statutory}_{b,j,t+1}(1-\zeta^{ded}_{b,j,t+1})+\zeta^{cred}_{b,j,t+1}\right]}.$$

1.4.3 Equilibrium Implications

1.4.3.1 Labor

The equalization of the marginal products of labor from Equation (38) between any two sectors j and k implies:

$$\Phi^{W}_{corp,j,t}A_{j,t}\frac{\zeta_j}{Y_{j,t}}\left(\frac{K_{j,t}}{L_{j,t}}\right)^{\alpha^{f}_{j,t}} = \Phi^{W}_{corp,k,t}A_{k,t}\frac{\zeta_k}{Y_{k,t}}\left(\frac{K_{k,t}}{L_{k,t}}\right)^{\alpha^{f}_{k,t}} \tag{42}$$

Define the shares of labor allocated to sectors $j \in \{1,\ldots,n-1\}$ as:

$$l_{j,t} = \frac{L_{j,t}}{L_t}$$

We can back out $l_{j,t}$ for each sector, which is equal to:

$$l_{j,t} = \frac{\Phi^{W}_{corp,j,t}\zeta_j}{\sum_{k=1}^{n}\Phi^{W}_{corp,k,t}\zeta_k}. \tag{43}$$

and using Equation (29) we can back out the amount of labor to the corporate and the pass-through businesses.

1.4.3.2 Capital

We use the FONC with respect to capital, equation 41, as well as Equation (29) and the marginal product of capital for the intermediate good production function in order to identify the share of capital that is allocated to each sector.

On the right side, we have $p_{j,t} = \zeta_{j,t}\frac{Y_t}{Y_{j,t}}$. The sector-specific TFP $A_{j,t+1}$ cancels out on

both sides as well.

$$\alpha^f_{j,t+1}\left(\frac{K_{j,t+1}}{L_{j,t+1}}\right)^{\alpha^f_{j,t+1}-1} = \frac{\Phi^R_{b,j,t+1}}{\zeta_{j,t+1}Y_{t+1}}K^{\alpha^f_{j,t+1}}_{j,t+1}L^{1-\alpha^f_{j,t+1}}_{j,t+1}$$

where the capital-to-labor ratio for the corporation on the left side is replaced with the sector capital-to-labor ratio (which is the same). This allows us to solve for the ratio of capital in sector j relative to sector 1 for all sectors j:

$$\frac{K_{j,t+1}}{K_{1,t+1}} = \frac{\zeta_{j,t+1}\alpha^f_{j,t+1}(\Phi^R_{j,t+1})^{-1}}{\zeta_{1,t+1}\alpha^f_{1,t+1}(\Phi^R_{1,t+1})^{-1}} \tag{44}$$

Adding up the ratios of capital in sector j relative to sector 1 for all j, we get:

$$\frac{K_{t+1}}{K_{1,t+1}} = \frac{\sum^n_{j=1}\left(\zeta_{j,t+1}\alpha^f_{j,t+1}(\Phi^R_{j,t+1})^{-1}\right)}{\zeta_{1,t+1}\alpha^f_{1,t+1}(\Phi^R_{1,t+1})^{-1}} \tag{45}$$

$$\frac{K_{1,t+1}}{K_{t+1}} = \frac{\zeta_{1,t+1}\alpha^f_{1,t+1}(\Phi^R_{1,t+1})^{-1}}{\sum^n_{j=1}\left(\zeta_{j,t+1}\alpha^f_{j,t+1}(\Phi^R_{j,t+1})^{-1}\right)} \tag{46}$$

which gives capital in sector 1 as a share of all capital, which is the condition that will allow us to allocate the economy-wide stock of productive capital to each sector.

1.4.4 Pass-Through Firms

The decisions of a sector j pass-through firm arise as a residual in this economy. Its demand for labor and capital inputs is determined by equations (43) and (46) and the parameter that determines the split of capital in corporate and pass-through, $\zeta^{income}_{b,j,t}$. Recall that investment and production credits, other expenses, and capital adjustment costs occur at the firm level; all other taxes/subsidies occur at the household level, so some

parameters in the equations above are zero, capturing that fact.

1.5 The Government

We assume that the government's policy schedule, ψ_t^T, which determines both current and future policy as of year t, is credible. The government collects taxes and makes its consumption and transfer spending as scheduled in ψ_t^T.

The government's income tax revenue, $T_{I,t}$, payroll tax revenue for Social Security and Medicare, $T_{P,t}$, consumption (or other) tax revenue, $T_{C,t}$, corporate or firm tax revenue $T_{corp,t}$ and estate tax revenue $T_{E,t}$ are

$$T_{I,t} = \int_S \tau_{I,t}\left(y_t^T(j,h,z,l,\iota,w_t), \tilde{r}_t a, tr_{OASI,t}(j,b,p_{t-j}^t), \iota\, oop_t, rc_t(j)\right) dX_t(s), \tag{47}$$

$$T_{P,t}(\tau_{O,t},\tau_{HI,t}) = \int_S \tau_{P,t}(y_t^T(j,h,z,l,\iota,w_t);\tau_{O,t},\tau_{HI,t})\, dX_t(s), \tag{48}$$

$$T_{C,t}(\tau_{C,t}) = \int_S \tau_{C,t}\,(\psi_t^C c)\, dX_t(s), \tag{49}$$

$$T_{corp,t} = \sum_b \sum_j T_{b,j,t} \tag{50}$$

$$T_{E,t} = \int_S (1-\delta_t(j,h))\tau_{E,t}(a' - \Xi(a'))] dX_t(s), \tag{51}$$

$$T_{S,t} = \int_S \tau_{state,t}\eta_1^y y_t^T(j,h,z,l,\iota,w_t)\, dX_t(s) \tag{52}$$

where $\tau_{O,t}$ is an OASDI payroll tax rate and $\tau_{HI,t}$ is a Medicare Hospital Insurance tax rate. η_1^y is the share of labor income that is subject to tax. $\tau_{corp,t}$ is a function which maps a history of capital stocks $K_{t-T_d+1}^{t+1}$ from $t - T_d + 1$ to $t + 1$ and labor demand to firm tax payments. $T_{S,t}$ are tax revenues collected by the state government.

Social Security transfer spending, $TR_{OASI,t}$, ACA premium subsidies, $M_{ACA,t}$, Medicare spending net of premiums, $M_{Mcare,t}$, Medicaid spending, $M_{Mcaid,t}$, and SNAP and

SSI transfers, SN_t and SSI_t, are

$$TR_{OASI,t} = \int_S tr_{OASI,t}(j, b, p^t_{t-j})\, dX_t(s), \tag{53}$$

$$M_{ACA,t} = \int_S \mathbf{1}_{[(i,y,j,a)=ACA]} \pi^{PremSub}_{ACA,t}(y^T_t) dX_t(s) \tag{54}$$

$$M_{Mcare,t} = \int_S \Big(\iota \cdot (m_t(j, h, d, i = Mcare) - oop_t(m, i = Mcare)) - p_{Mcare,t} \Big)\, dX_t(s), \tag{55}$$

$$M_{Mcaid,t} = \int_S \Big(\mathbf{1}_{j<65, \iota=1} \Big(m_t(j, h, d, i = Mcaid, X_t) - oop_t(m, i = Mcaid) \Big) + \mathbf{1}_{j\geq 65} \Big(p_{Mcare,t} + \iota \cdot (oop_t(m, i = Mcare) - oop_t(m, i = Mcaid)) \Big) \Big)\, dX_t(s), \tag{56}$$

$$TR_{SNAP,t} = \int_S SN_t(s, l)\, dX_t(s),$$

$$TR_{SSI,t} = \int_S SSI_t(s, l)\, dX_t(s), \tag{57}$$

$$\tag{58}$$

Exogenous outlays $C_{G,t}$ do not depend on the household distribution. For those who qualify for Medicaid and who are younger than 65, Medicaid covers medical expenses in excess of the out-of-pocket spending requirements. For those who are 65 and older, Medicare is the primary payer, which means that Medicare is responsible for covering the bulk of health care expenses, while Medicaid only covers Medicare premiums, $p_{Mcare,t}$, and the difference in out-of-pocket spending between what Medicaid and Medicare require, $oop_t(m, i = Mcare) - oop_t(m, i = Mcaid)$.

1.5.0.1 Government Debt and Interest Payments

The government's primary net-of-interest deficit pd_t is

$$pd_t = \big[C_{G,t} + TR_{OASI,t} + M_{ACA,t} + M_{Mcare,t} + \varrho^M_t M_{Mcaid,t} + \varrho^{SN}_t TR_{SNAP,t} + TR_{SSI,t} - T_{I,t} - T_{P,t}(\tau_{O,t}, \tau_{HI,t}) - T_{C,t}(\tau_{C,t}) - T_{corp,t} - T_{E,t} - T_{exog,t} + mm_t \big], \tag{59}$$

where ϱ_t^M (ϱ_t^{SN}) is the share of total Medicaid (SNAP) expenses borne by the federal government and $T_{exog,t}$ is the aggregate of a number of exogenous sources of revenue that are not explicitly modeled in the dynamic OLG framework (including gift taxes, excise taxes, and a few other revenue categories).[11] The states' share of Medicaid (SNAP) expenses is thus $1 - \varrho_t^M$ ($1 - \varrho_t^{SN}$) and is financed by the flat state income tax $\tau_{state,t}$. As we will sometimes exogenously forecast the path of government debt, we allow for "magic money", mm_t. When debt is exogenous, mm_t will then be determined by (59). When debt is endogenous, then mm_t will be exogenous.

The state government always runs a balanced budget so that in each period:

$$T_{S,t} = (1 - \varrho_t^M)\, M_{Mcaid,t} + (1 - \varrho_t^{SN}) TR_{SNAP,t} \tag{60}$$

where η_1^y is the share of taxable labor income that is taxable by states.

Each period the government must finance any deficit by issuing new debt. It must also issue new debt to replace retiring debt. We assume that there is a set of bonds with maturities of 1 through T_m years that the government can choose to issue. We obtain current yield curves on U.S. government debt and forecast expected future yield curves using Microsim: $yc_t : \mathcal{T}_{\Updownarrow} \to \mathbb{R}$, where $\mathcal{T}_{\Updownarrow} = \{1, 2, ..., T_m\}$.[12]

We assume that the government issues debt with initial maturities in $IM \subset \mathcal{T}_{\Updownarrow}$. Based on current U.S. government issuance, we set $IM = \{1, 2, 3, 5, 7, 10, 30\}$.

At any time t, suppose the government enters the period with an outstanding debt maturity schedule that is a $(T_m \times 1)$ vector d_t and an effective coupon rate on its outstanding debt that is a $(T_m \times 1)$ vector ey_t. The net interest the government owes that period is $NI_t^G = d_t' ey_t$. Total government debt outstanding is $D_t^G = d_t' 1_{(T_m \times 1)}$ and evolves according

[11] The equations in this section describe the baseline. Certain policy experiments add budget categories that are not represented here, such as wealth tax revenue, outlays for universal health insurance, and an additional HI payroll tax that finances them.

[12] The Microsim constructs its projections of the yield curve using the methodology developed by Nelson and Siegel (1987).

to

$$D_{t+1}^{G} = \frac{D_t^G + NI_t^G + pd_t}{1 + \pi_t^{CPI}}, \tag{61}$$

where π_t^{CPI} is CPI-U inflation. Interest and the deficit are paid in nominal dollars, so the end-of-year nominal debt is deflated by CPI-U inflation to convert it back to model units. To finance this new debt level D_{t+1}^G the government must issue new debt with face value $N_t = d_t(1) + \Delta D_{t+1}$.

New debt is allocated so that the maturity distribution stays close to its distribution at T_0. We group maturities into buckets, one for each issue maturity $IM_k \in IM$: $B(IM_k) = \{IM_{k-1} + 1, \ldots, IM_k\}$ with $IM_0 = 0$, so that the buckets are $\{1\}$, $\{2\}$, $\{3\}$, $\{4, 5\}$, $\{6, 7\}$, $\{8, 9, 10\}$ and $\{11, \ldots, 30\}$. The target share of each bucket is fixed at its share of debt at T_0,

$$\omega(IM_k) = \frac{\sum_{m \in B(IM_k)} d_{T_0}(m)}{D_{T_0}^G}. \tag{62}$$

After existing debt ages one year, the gap between the target and the aged debt in each bucket is

$$g_t(IM_k) = \omega(IM_k)\Big(\sum_{m=1}^{T_m - 1} d_t(m+1) + N_t\Big) - \sum_{m \in B(IM_k)} d_t(m+1). \tag{63}$$

New debt fills these gaps in order of maturity, $IM_1, IM_2, \ldots$, until the new issues are used up:

$$nd_t(IM_k) = \max\Big\{0,\ \min\Big\{g_t(IM_k),\ N_t - \sum_{k' < k} nd_t(IM_{k'})\Big\}\Big\}. \tag{64}$$

Because the gaps sum to N_t, every bucket reaches its target when all gaps are positive, and the order of filling matters only when the aged debt in some bucket exceeds its target. Any new debt left over is issued at a maturity of one year. If N_t is negative, so that the surplus exceeds the maturing debt, existing debt is instead retired in proportion to the amount outstanding at each maturity. We set $nd_t(m) = 0$ for $m \notin IM$, so that nd_t is defined for all maturities. The law of motion for debt at maturity m is then $d_{t+1}(m) = nd_t(m) + d_t(m+1)$. The effective coupon then evolves as a weighted average of the rate on old debt and new

debt:

$$ey_{t+1}(m) = \frac{d_t(m+1)}{d_{t+1}(m)} ey_t(m+1) + \frac{nd_t(m)}{d_{t+1}(m)} yc_t(m) \tag{65}$$

The nominal effective rate on government debt is then $i^D_{t+1} = \frac{NI^G_{t+1}}{D^G_{t+1}}$, which is in the time t information set. The real effective rate on government debt deflates it by CPI-U inflation,

$$1 + r^D_{t+1} = \frac{1 + i^D_{t+1}}{1 + \pi^{CPI}_{t+1}}. \tag{66}$$

We assume that government bonds are held by both domestic and foreign investors and that foreign investors hold only government bonds and not domestic private capital. The amount of foreign wealth invested in government bonds at any time t is W^F_t. We assume that new foreign-owned holdings of U.S. federal debt grow as a share of new, non-rolled-over issues of debt so that foreign holdings obey the following law of motion:

$$W^F_{t+1} = \frac{W^F_t + \phi^D_t \left(N_t - d_t(1)\right)}{1 + \pi^{CPI}_t}, \tag{67}$$

where $N_t - d_t(1)$ is net new issues of debt in year t (total new issues less maturing debt), ϕ^D_t is the share of net new issues purchased by foreign investors, and π^{CPI}_t is CPI-U inflation, which converts nominal holdings back to model units. Because the government issues net new debt every year, W^F_t changes every year of the transition path, including the years after T_c. We set ϕ^D_t to match the historical share of new U.S. federal debt that has been purchased by foreign investors, which is around 30 percent.

1.5.1 Mutual Fund Asset Markets

1.5.1.1 Dividends

A representative financial intermediary manages a mutual fund, pooling the households' savings (net of depreciation) into deposits to be invested in capital markets, that is, in government bonds and physical capital. Government bonds earn a lower "safe" interest

rate relative to the return on productive capital. Since there is no aggregate uncertainty in the model, we assume the share of government bonds in the portfolio managed by the mutual fund is such that it clears the government's need for funding.

Aggregate deposits are:

$$A_{t+1} = \int_{\mathbf{s_t}} a'(s, \Psi_t^{t+J_D-j}) dX_t(\mathbf{s_t}) \tag{68}$$

In period t, the mutual fund uses A_{t+1} to purchase K_{t+1} units of physical capital and holds a stock $D_{t+1}^G - W_{t+1}^F$ of government bonds. Given the price of capital fluctuations, the mutual fund realizes capital gains or losses, $\Delta q_t = q_t - q_{t-1}$. The fund pays households the principal and a return on the portfolio chosen in the previous period, $(1 + r_t)A_t$.

The zero-profit condition on the financial intermediary implies that households receive a return on their deposits equal to:

$$\begin{aligned} r_t = & \left.\frac{R_{corp,t}}{A_t}\right\} \text{return on } K_{corp,t} = r_t^{corp} \\ & + \left.\frac{R_{pass,t}}{A_t}\right\} \text{return on } K_{pass,t} = r_t^{pass} \\ & + \left.\frac{r_t^D(D_t^G - W_t^F)}{A_t}\right\} \text{return on } (D_t^G - W_t^F) = r_t^G \\ & + \left.\frac{\Delta q_t K_t}{A_t}\right\} \text{return on capital gains } = r_t^C \end{aligned} \tag{69}$$

Because r_t^D is the real effective rate, r_t is the real return on deposits that enters the household budget constraint (11).

1.5.1.2 Taxable Income

The dividends that the household gets, however, are not the same as their taxable income, which can vary significantly from the actual payments. First, the mutual fund provides the taxable return on the portfolio that originates from government bonds. Interest

is taxed on its nominal value, so this return is $i_t^G = \frac{i_t^D(D_t^G - W_t^F)}{A_t}$ rather than the real r_t^G. This dividend income is entirely taxed at the ordinary rate.

Second, the mutual fund reports the taxable income from corporate sources: r_t^{corp}. Note that these are equal to the dividends paid by the corporation (and capital gains on corporate capital). All credits and deductions have already been applied before the business tax was applied. Whatever is left over is taxable income for the household. Most of this money is taxed at the preferred rate; however, some of it may be taxed at the ordinary rate.

Third, the mutual fund reports the taxable income from pass-through sources of income: r_t^{pass}. Unlike corporations, pass-through taxable income is not the amount of money that is being paid out in dividends, but generally is equal to the dividends minus tax deductions. We do not apply any credits beyond investment credits that may be included in the capital investment allowance schedule. Additional deductions may be applied at the household level. Most of this money is treated as ordinary income for the purposes of taxation; however, the share is determined by the household problem.

Fourth, the mutual fund reports capital gains, $r_t^C = \frac{\Delta q_t K_t}{A_t}$, some fraction of which may or may not be taxed at the preferred rate.

1.6 Aggregation

Total private wealth, A_{t+1}, federal debt held by the public, D_t^G, domestic capital stock, K_t, labor supply in efficiency units, L_t, and aggregate medical expenditures M_t are

$$A_{t+1} = \int_S a' \, dX_t(s), \tag{70}$$

$$K_{t+1} = A_{t+1} + W_{t+1}^F - D_{t+1}^G, \tag{71}$$

$$L_t = \int_S e(s)(\Omega_{a,t}(j) l_{\max} - l(s, \Psi_t^{t+J_D-j})) \, dX_t(s), \tag{72}$$

$$M_t = \int_S \frac{\iota \cdot m_t(j, h, d, i, X_t)}{1 - \kappa_i} \, dX_t(s), \tag{73}$$

1.7 Competitive Equilibrium

Let the set of prices be $p_t = \{r_t, r_t^{corp}, r_t^{pass}, r_t^G, i_t^G, r_t^C, r_t^K, r_t^D, i_t^D, w_t, p_t^p, p_{j,t}\}$. Let the set of government policies, ψ_t, be as defined in Equation (1). Here r_t^K is the return on physical capital, p_t^p collects the private insurance premiums $p_{p,t}(j)$ set by the insurers' zero-profit condition (27), and the scaling factors $\pi_{j,t}$ are the values $\pi_t^s(j)$ of the scaling vector in equation (25). Given an initial distribution at date T_0, X_{T_0}, initial debt $D_{T_0}^G$, maturity schedule d_{T_0}, effective coupon curve ey_{T_0} and foreign wealth $W_{T_0}^F$, and history of capital choices $\{K_{b,j,t}\}_{t=T_0-T_d}^{T_0}$ and a set of scaling factors and yield curves, $\{\pi_{j,t}, yc_t\}_{t=T_0}^{\infty}$, a competitive equilibrium at time T_0 is a sequence of sets $\{X_{t+1}, K_{t+1}, L_t, \psi_t, p_t, D_{t+1}^G, W_{t+1}^F, mm_t\}_{t=T_0}^{\infty}$ and optimal policies for the household and firm, respectively, Γ_h and $\Gamma_{b,j}^f$ such that:

1. Markets clear: eqs (70)-(73) $\forall t = T_0, \ldots, \infty$
2. $\Gamma_h, \{\Gamma_{b,j}^f\}_{\{corp,pass\},\{1,\ldots,n\}}, Y_{T_0}$ solve the household, intermediate and final goods firms' problems, respectively
3. X_{t+1} updates according to eq (26) $\forall t = T_0, \ldots, \infty$

4. The government budget constraint (59) holds for all $t = T_0, ..., \infty$, given (67) and either D^G_{t+1} or mm_t exogenous.

5. The state government budget constraint (60) holds for all $t = T_0, ..., \infty$

6. Mutual funds earn zero profits for all $t = T_0, ..., \infty$: (69)

7. Health insurers earn zero profits for all $t = T_0, ..., \infty$: (27)

The economy is in a stationary (steady-state) equilibrium at time t if, in addition, $X_k = X_{k+1}$, $p_k = p_{k+1}$, $\pi_{j,k} = \pi_{j,k+1}$, $D^G_{k+1} = D^G_k$, $mm_{k+1} = mm_k$ and $\psi_k = \psi_{k+1}$ for all $k = t, \ldots, \infty$.

1.7.1 Competitive Equilibrium with Terminal Steady State

Given an initial distribution at date T_0, X_{T_0}, initial debt $D^G_{T_0}$ and foreign wealth $W^F_{T_0}$, and history of capital choices $\{K_{b,j,t}\}^{T_0}_{t=T_0-T_d}$ and a set of scaling factors $\{\pi_{j,t}\}^{\infty}_{t=T_0}$, a competitive equilibrium at time T_0 with Terminal Steady State is a Competitive Equilibrium such that there exists a T such that $X_k = X_{k+1}$, $p_k = p_{k+1}$, $\pi_{j,k} = \pi_{j,k+1}$, $D^G_{k+1} = D^G_k$, $mm_{k+1} = mm_k$ and $\psi_k = \psi_{k+1}$ for all $k > T$.

An Initial Steady State is simply a Competitive Equilibrium with Terminal Steady State such that the steady state date, $T = T_0$.

1.8 Computing an Initial Steady State

This subsection and the next two list the steps of the solution algorithms. Appendix C describes the numerical methods used within each step.

Given a set of parameters θ, a set of government policies, ψ_{T_0}, and a desired debt level $D^G_{T_0}$ and level of foreign investment $W^F_{T_0}$, to compute an Initial Steady State we follow the steps below. The desired debt level $D^G_{T_0}$ is the end-of-year debt held by the public in the data. Because debt is set to this target, the Initial Steady State does not impose the stationarity condition $D^G_{T_0+1} = D^G_{T_0}$.

1. Set the scaling factors, $\pi_{j,T_0}\ \forall\ j \in J$

2. Guess a price vector p_{T_0}, a state tax τ_{state,T_0}, a survival function δ and a household distribution X_{T_0}.

3. Solve the household's problem.

4. Compute law of motion for households and update the distribution of households.

5. Aggregate household policies to get aggregate savings, labor and insurance demand.

6. Back out Capital Supply from Aggregate Savings using $D^G_{T_0}$ and $W^F_{T_0}$.

7. Apportion labor and capital to intermediate firms using (29), (43) and (44)-(46). Solve for Aggregate Output Y_{T_0} and interest rate vector $\tilde{r}_{T_0}$

8. Find "new guess" of prices, $p_{T_0} = \{r_{T_0}, \tilde{r}_{T_0}, w_{T_0}, p^p_{T_0}, p_{j,T_0}\}$ using (69), (38), (28) and (27). Update the state tax rate using (60). Check if the new guesses are close to guesses in Step 2. Likewise check if model survival rates (conditional on age but not health) are close to those in the data. If either of these checks fail, take new guesses and go to Step 2.

9. Back out a magic money amount mm_{T_0} using (59)

Section 2.1 describes how we choose the internally calibrated parameters in θ.

1.9 Computing a Baseline Transition Path

Given an initial year, T_0, a closure year T_c, and a final steady state year, T_f, a set of parameters $\{\theta_t\}_{t=T_0}^{T_f}$ (including health insurance premium growth rates ν_i), a set of government policies, $\{\psi_t\}_{t=T_0}^{T_c}$, a desired age-dependent population level $\{x^{est}_{j,t}\}_{t=T_0}^{T_c}$ for all $j \in [J_B, J_D]$, a desired debt level $\{D^G_t\}_{t=T_0}^{T_c}$ and an initial level of foreign investment $W^F_{T_0}$, to compute a Baseline Transition Path we follow these steps:

1. Compute an ISS using steps above. This will provide an initial distribution X_{T_0} and history of capital choices $\{K_{b,j,t}\}_{t=T_0-T_d}^{T_0}$.

2. Set $D_t^G = D_{t-1}^G$ for all $T_f \geq t > T_c$. Foreign holdings W_t^F continue to follow (67) in every year.

3. Compute the final steady state at time T_f using the same steps as the ISS above. This will provide a set of prices and policies p_{T_f} and ψ_{T_f}.

4. Guess survival rate function $\{\delta_t\}_{t=T_0}^{T_f}$ [13]

5. Guess a path of prices, household distributions and state tax rates for all $t \in \{T_0, ..., T_f - 1\}$.

6. Iterate backwards from T_f to T_0, computing the optimal household's and firm's policies at each year: $\{\Gamma_{h,t}, \Gamma_{f,t}\}$.

7. Use $\{\Gamma_{h,t}, \Gamma_{f,t}\}_{t=T_0}^{T_f}$ to update X_t and capital choices $\{K_{b,j,t}\}_{t=T_0}^{T_f}$.

8. Check market clearing conditions for each $t \in \{T_0, ..., T_f - 1\}$ by: aggregating household policies to get aggregate savings, labor and insurance demand; backing out Capital Supply from Aggregate Savings using D_t^G and W_t^F; apportioning labor and capital to intermediate firms using (29), (43) and (44)-(46) and solving for Aggregate Output Y_t and interest rate vector $\tilde{r}_t$.

9. Find "new guess" of prices, $p_t = \{r_t, \tilde{r}_t, w_t, p_t^p, p_{j,t}\}$ using (69), (38), (28) and (27). Likewise, update guesses of state tax rates and survival functions δ. Check if new guesses are close to the guesses in Steps 4–5. If not, take new guesses and go to Step 4.

10. Back out a magic money amount $\{mm_t\}_{t=T_0}^{T_f}$ using (59)

[13] The δs are included in the set of parameters $\{\theta_t\}_{t=T_0}^{T_f}$ and δ_{T_0} from this set is used to compute ISS. For subsequent steps though we will adjust the δs.

Let the operator BT take sequences of vectors of parameters, $\{\theta_t\}_{t=T_0}^{T_f}$, into sequences of vectors in $\{\mathbb{R}^{N^I}\}_{t=T_0}^{T_f}$ as described by this implementation. In other words, for a given sequence of parameters $\{\theta_t\}_{t=T_0}^{T_f}$, $BT(\{\theta_t\}_{t=T_0}^{T_f})$ will find an Initial Steady State, compute a Competitive Equilibrium with Terminal Steady State and magic money and then output a sequence of simulated data.

1.10 Computing a Policy Transition Path

We wish to compute the effects of a change in taxes, transfers and government spending. We will keep ν_i at its baseline levels, and mm_i at its baseline levels for all years before the final steady state. We assume that the new policy parameters ψ'_t can vary arbitrarily from the baseline parameters ψ_t. During closure we require $\psi'_t = \psi'_{t-1}\ \forall t > T_c$ with one exception: we will allow a tax rate (currently a consumption tax, $\hat{\tau}_{C,t}$) to vary year by year during and after closure in order to ensure the budget balances period by period with no change in government debt for each year $T_c \leq t < T_f$. In the final steady state, the consumption tax rate is held at its value in $T_f - 1$, so that it does not jump in the last year, and magic money closes any remaining budget imbalance.

After computing a Baseline Transition Path, we can compute a Policy Transition Path with the same given initial year, T_0, closure year T_c, final steady state year, T_f, set of parameters $\{\theta_t\}_{t=T_0}^{T_f}$, a desired age-dependent population level $\{x_t^{est}\}_{t=T_0}^{T_c}$ and new set of government policies: $\{\psi'_t\}_{t=T_0}^{T_c}$ by following these steps:

1. From the baseline transition path, obtain the path of magic money, scaling factors and survival rates, $\{mm_t, \pi_{j,t}, \delta_t\}_{t=T_0}^{T_f} \in BT(\{\theta_t\}_{t=T_0}^{T_f})$, as well as the initial distribution X_{T_0}, the history of capital choices $\{K_{b,j,t}\}_{t=T_0-T_d}^{T_0}$, and the initial debt level $D_{T_0}^G$.

2. Guess a $D_{T_c}^G$ and set $D_t^G = D_{t-1}^G$ for all $T_f \geq t > T_c$. Foreign holdings W_t^F follow (67) in every year.

3. Compute the final steady state at time T_f by following:

(a) Guess a price vector p_{T_f}, a state tax rate τ_{state,T_f} and a household distribution X_{T_f}. Set the consumption tax rate to its current value in the year before the final steady state, $\hat{\tau}_{C,T_f} = \hat{\tau}_{C,T_f-1}$.

(b) Solve the household's problem.

(c) Compute law of motion for households and update the steady state distribution of households.

(d) Aggregate household policies to get aggregate savings, labor and insurance demand.

(e) Back out Capital Supply from Aggregate Savings using $D^G_{T_f}$ and $W^F_{T_f}$.

(f) Apportion labor and capital to intermediate firms using (29), (43) and (44)-(46). Solve for Aggregate Output Y_{T_f} and interest rate vector $\tilde{r}_{T_f}$

(g) Find "new guess" of prices, $p_{T_f} = \{r_{T_f}, \tilde{r}_{T_f}, w_{T_f}, p^p_{T_f}, p_{j,T_f}\}$ using (69), (38), (28) and (27) and similarly for state tax rates. Check if new guesses are close to the guesses in Step 3a. If not, take new guesses and go to Step 3a.

(h) Back out a magic money amount mm_{T_f} using (59), so that magic money closes any budget imbalance that remains in the final steady state at the consumption tax rate $\hat{\tau}_{C,T_f}$.

4. Guess a path of prices, household distributions, state taxes and consumption taxes for all $t \in \{T_0, ..., T_f - 1\}$.

5. Iterate backwards from T_f to T_0, computing the optimal household's and firm's policies at each year: $\{\Gamma_{h,t}, \Gamma_{f,t}\}$.

6. Use $\{\Gamma_{h,t}, \Gamma_{f,t}\}_{t=T_0}^{T_f}$ to update X_t and obtain capital choices $\{K_{b,j,t}\}_{t=T_0}^{T_f}$.

7. Check market clearing conditions for each $t \in \{T_0, ..., T_f - 1\}$ by: aggregating household policies to get aggregate savings, labor and insurance demand; backing out

Capital Supply from Aggregate Savings using D_t^G and W_t^F; apportioning labor and capital to intermediate firms using (29), (43) and (44)-(46) and solving for Aggregate Output Y_t and interest rate vector $\tilde{r}_t$.

8. Find "new guess" of prices, $p_t = \{r_t, \tilde{r}_t, w_t, p_t^p, p_{j,t}\}$ using (69), (38), (28) and (27). Likewise, update guesses of $\tau_{state,t}$ and $\tau_{C,t}$ using (60) and (59). Check if new guesses are close to the guesses in Step 3a. If not, take new guesses and go to Step 3.

2 Calibration and Model Performance

2.1 Calibration and Parameterization of the Initial Steady State

Let the operator ISS take a vector of parameters, θ, into a vector of moments in $\mathbb{R}^{N^I}$. For a given θ, $ISS(\theta)$ computes an Initial Steady State with the steps of Section 1.8 and returns the moments that it simulates.[14] Let $\mathcal{M}^I \in \mathbb{R}^{N^I}$ be the vector of targeted values of those moments. The internally calibrated parameters, θ^I, satisfy

$$\left|ISS(\theta^I)_i - \mathcal{M}^I_i\right| \leq \epsilon_i, \qquad i = 1, \ldots, N^I, \tag{74}$$

where $\epsilon_i > 0$ is the tolerance for moment i. Table 1 pairs each internally calibrated parameter with the moment that it targets. The rest of this section reports the target values.

We find θ^I by iterating on a guess, θ_n. Each iteration computes $ISS(\theta_n)$ once and then updates the parameters one at a time, in the order of Table 1. Each update uses the values that earlier updates in the same iteration have produced. For example, the update of γ uses the new value of α, and the fit of γ^{ht} uses the new value of δ^{ht}. Most parameters respond only to the gap between their own moment and its target. The two exceptions are the health-transition parameters. The parameters δ^{ht} take a joint quasi-Newton step on four spending-ratio moments, and γ^{ht} is fit by least squares given δ^{ht} (Section 2.6.4).

The iteration runs in three phases:

1. **Asset phase.** Only the Medicaid asset schedule updates. Every other parameter stays at its initial value, and the age factor of the Medicaid income test is one at every age. The phase ends once the schedule is unchanged for three consecutive iterations, or after 300 iterations.

2. **Jacobian phase.** Only δ^{ht} moves. We estimate the Jacobian of the four spending-

[14] ISS also depends on the externally set parameters. For notational simplicity, we suppress that dependence.

ratio moments with respect to $\delta^{ht}(1), \ldots, \delta^{ht}(4)$ by finite differences, which takes five solves of ISS. The phase is skipped when a Jacobian stored from an earlier run is available. The phase recurs when the quasi-Newton step repeatedly falls back to a gap step or predicts the moments poorly. At most two Jacobian estimates take place, both within the first ten iterations after the asset phase.

3. **Main phase.** Every parameter in Table 1 updates except the Medicaid asset schedule, which keeps its value from the asset phase.

The main phase stops as soon as every moment satisfies Equation (74) in the same iteration. It also stops when progress stalls. Let

$$S_n = \sum_{i=1}^{N^I} \left(\frac{ISS(\theta_n)_i - \mathcal{M}_i^I}{\epsilon_i} \right)^2$$

measure the fit of iteration n. Progress stalls when S_n fails, for 15 consecutive iterations, to fall at least 1 percent below its best earlier value. An iterate is acceptable when every moment lies within $2\epsilon_i$ of its target and the uninsured and ACA enrollment moments lie within ϵ_i. On a stall, the run adopts the acceptable iterate that best fits the spending-ratio, uninsured and Medicaid moments. If no iterate is acceptable, the run continues. Iterations of the Jacobian phase count toward neither stopping rule. The main phase, including the Jacobian phase, runs at most 500 iterations. If neither stopping rule applies within that limit, the run ends at its last iterate and reports that it has not converged.

For an initial steady-state, some model variables, such as government outlays and government debt, are set to match data from PWBM's Microsim model. In some cases, the OLG model takes data from the Microsim model directly. In other cases, the OLG model will first project Microsim data onto a small dimension before using it in the model. This is done, for example, for any data that is conditional on demographic variables.

In this section, we discuss the calibration of the parameters and exogenous variables that are not based solely on the Microsim and mention in passing those that are set using

Table 1: Internally calibrated parameters of the initial steady state

Parameter	Target moment	Update rule	Phase
α	Average hours worked	$\alpha\,\mathcal{M}/m$	Main
γ	Coefficient of relative risk aversion	Partial step toward $1 + (\mathcal{M} - 1)/\alpha$	Main
$l_{\max}$	Average Frisch elasticity	$\bar{h}^*\big(1 + \mathcal{M}\gamma/(1 - \alpha + \alpha\gamma)\big)/\bar{\Omega}$	Main
$\delta^{ht}(h)$, $h \leq 4$	Spending ratio, uninsured to insured, ages 26–64, health state h	Damped quasi-Newton step on all four ratios	Jacobian, main
$\gamma^{ht}(h, h')$	Health transitions of the uninsured, ages 21–64	Least squares given δ^{ht}; partial step; fixed after three fits	Main
ζ	Spending ratio, uninsured to insured, ages 26–64, health state 5	$\zeta\big(1 + \lambda\,\mathrm{clip}\big((\mathcal{M} - \bar{m})/|\mathcal{M}|\big)\big)$	Main
β	Capital–output ratio	$\beta - k\,(m - \mathcal{M})$	Main
Dollars per model unit	Average labor income	Damped gap step with gain $1/(1 + 0.01n)$	Main
$\underline{y}^{ESI}$	Uninsured rate, ages 26–64	$\underline{y}^{ESI}\big(1 + \lambda\,(\mathrm{clip}(\mathcal{M}/\bar{m}) - 1)\big)$	Main
aca_{cutoff}	ACA enrollment, ages 26–64	As for $\underline{y}^{ESI}$	Main
Medicaid income-test age factor	Medicaid enrollment by age group	Step on the enrollment gap, along a piecewise-linear age profile	Main
Medicaid asset schedule	Medicaid enrollment by age group	One grid step per age group; monotone in age	Asset
ω_j^{HI}	Uninsured rate by age group	Damped rescaling by the clipped relative gap, smoothed across ages	Main
Top-earner multiple	Top 1 percent share of earnings	As for $\underline{y}^{ESI}$, within $[1, 35]$	Main
Multi-group runs only (Appendix B)			
Aggregate labor scale	Average wage	Gap step with decaying gain	Main
Worker-type productivity	Earnings ratios across skills and between domestic and foreign workers	Damped gap step with decaying gain	Main
Productivity by experience	Shape of the earnings profile by age, by skill	Rescaling by the ratio of normalized profiles	Main
Population scale by skill	Population share by skill	Damped step $\mathcal{M}/m$ with decaying gain	Main

Notes: Parameters appear in update order. m is the model moment and $\mathcal{M}$ its target. $\bar{m}$ is an exponentially smoothed m. n is the iteration. $\bar{h}^*$ is the hours target. k and λ are fixed gains, and λ shrinks when the gap changes sign. $\delta^{ht}(5)$ is fixed at one. The phases are those of Section 2.1.

the Microsim model.

We calibrate the model's initial steady state to the 2024 U.S. economy with a fiscal policy that is close to the policy prevailing in 2024. In the initial steady state, the economy is assumed to be on a balanced growth path with a constant labor-augmenting productivity growth rate, μ. Individual variables other than working hours are thus growth-adjusted by $(1+\mu)^{-t}$ and aggregate variables are adjusted by $(1+\mu)^{-t}$. We set μ to 0.62 percent, which is based on Microsim projections.

2.2 Demographics

We normalize the measure of households in the initial steady state ($t = T_0$) to unity:

$$\int_S dX_{T_0} = 1.0,$$

Households enter the economy and start working at age $J_B = 21$ and can live to age $J_D = 100$. In the baseline, we assume that households retire and start claiming OASI benefits at current law full-retirement age $J_{R,t} = 67$, and they become eligible to enroll in Medicare at $J_{Mcare,t} = 65$ (see Table 2). Household's OASI benefits are calculated on the basis of its growth-adjusted earnings between ages 21 and $J_{R,t} - 1$.[15]

To estimate the average household size, we use data from the Microsim to estimate the average number of adults Ω_{a,T_0} and the average number of children Ω_{c,T_0} by age of the head of household. Figure 1 shows the resulting average number of adults and children by the age of the head of household from the data.

From the Microsim data, for each year $t \in \{T_0, \ldots, T_f\}$, we then create $(J \times 1)$ vectors of the number of households by age, $\hat{x}_t^{\text{microsim}}$, and of the numbers of households that die, de_t, emigrate, em_t, and immigrate, im_t. The model explicitly accounts for death, emigra-

[15] In the current Social Security system, AIME is calculated as the average of the highest 35 years of growth-adjusted earnings. However, keeping the previous 35 highest earnings as the household's state variables would make the household problem computationally intractable. In the model economy, therefore, AIME is approximated by the average of growth-adjusted earnings of all ages before $J_{R,t}$.

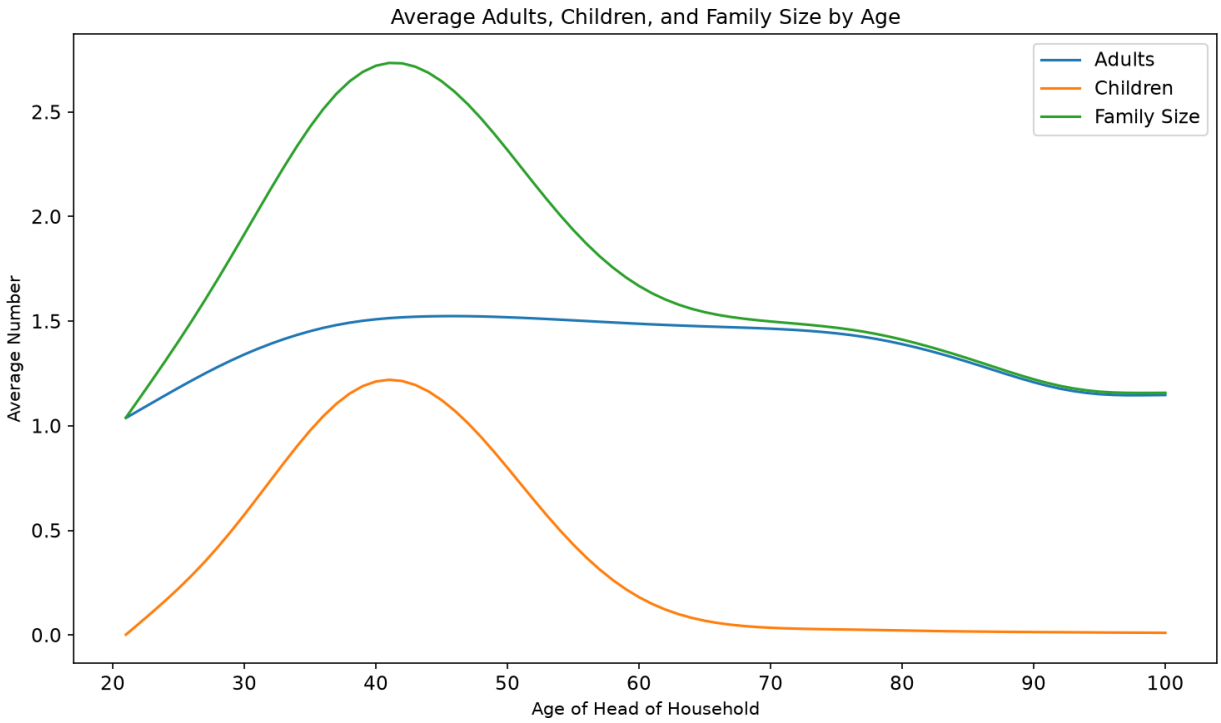


Figure 1: Average Number of Adults and Children per Household by Age of Head of Household in the initial steady state

Source: Penn Wharton Budget Model Microsim, Demographics Interface calculations for 2024.

tion and immigration but not for other entry and exit of households (such as marriage, divorce or death of the head but not the spouse). We use the scaling vector π_t^s, defined in equation (25) of Section 1.2.3, to adjust the model's number of households at each age so that it matches the data.

2.3 Preferences

We assume that the utility function is a combination of Cobb-Douglas and constant relative risk aversion (CRRA) preferences, which is consistent with a growth economy

$$u(c,l) = \frac{\left[c^{\alpha} l^{1-\alpha}\right]^{1-\gamma}}{1-\gamma}. \tag{75}$$

Table 2: Demographic and Preferences Parameters for the initial steady state

Parameter		Value	Comment
Demographics			
Maximum age	J^{max}	100	
Minimum age to receive OASI benefits	J_R	67	Full retirement age for OASI benefits
Minimum age to receive Medicare benefits	J_{Mcare}	65	Medicare eligibility age
Productivity growth rate	μ	0.006	Microsim projection
Health transition probabilities	P		See Section 2.6.4
Conditional survival rates	s		
Average number of Adults by age	$\Omega_{a,ISS}$		See Section 2.2
Average number of Children by age	$\Omega_{c,ISS}$		
Preferences			
Risk aversion parameter	γ	2.669	Joint targets: CRRA = 2.0,
Consumption share parameter	α	0.599	Frisch elasticity = 0.5,
Maximum leisure hours	l^{max}	1.183	average hours of work = 1.0
Discount factor	β	0.980	Target: K/Y = 3.0
Growth-adjusted discount factor	$\tilde{\beta}$	0.974	$\tilde{\beta} = \beta(1+\mu)^{\alpha(1-\gamma)}$
Minimum consumption	$\underline{c}$	0.082	\$11,600 annual minimum consumption
\$-per-model-unit	dpu	141,710	
Value of death	ζ	-462.814	See Section 2.6

Notes: Values are in model units unless otherwise noted; \$-per-model-unit (dpu) converts one model unit into dollars.
Source: Penn Wharton Budget Model.

We jointly calibrate the preference parameters α and γ and the maximum leisure hours per adult, $l_{\max}$, to match three targets in the baseline steady state: a coefficient of relative risk aversion of 2.0, an hours-weighted average Frisch elasticity of labor supply of 0.5, and average hours worked of 1.0 among households that work. The hours target normalizes the unit of hours and is not matched to data.[16] Our choice for risk aversion of 2.0 is roughly in the middle of the range typically used in the macro public finance literature, and requires setting $\gamma = 2.669$.[17]

The hours and Frisch targets together give $\alpha = 0.599$ and $l_{\max} = 1.183$; neither param-

[16]The coefficient of relative risk aversion (CRRA) can be calculated as $(1 - \alpha + \alpha\gamma)$. A working household's Frisch elasticity is $\frac{(1-\alpha+\alpha\gamma)}{\gamma}\frac{l}{h}$, where l is its leisure and h its hours worked. Averaging over working households with weights h gives $\frac{(1-\alpha+\alpha\gamma)}{\gamma}\frac{l_{\max}\bar{\Omega}-\bar{h}}{\bar{h}}$, where $\bar{h}$ is the average hours worked by households that work and $l_{\max}\bar{\Omega}$ is their average time endowment, with $\bar{\Omega}$ their average number of adults.

[17]For example, Domeij and Heathcote (2004) use 1.0; İmrohoroğlu et al. (1995) use 2.0; and Auerbach and Kotlikoff (1987) and Conesa et al. (2009) use 4.0.

eter matches a target on its own. In the iteration, α is updated to close the gap in average hours, and $l_{\max}$ is set to the time endowment at which target hours imply the target Frisch elasticity (Table 1). Both targets therefore hold only at the fixed point. A Frisch elasticity of 0.5 is consistent with the literature surveyed in Reichling and Whalen (2012).[18]

We choose the discount factor, β, so that the capital–output ratio, K_t/Y_t, in the benchmark economy is 3.0, which is commonly used in the literature. The growth adjusted discount factor $\tilde{\beta} = \beta(1+\mu)^{\alpha(1-\gamma)}$ can then be calculated to equal 0.974.

Government programs provide a consumption floor $\underline{c}$ that, depending on the reason for low resource, will pay benefits through Medicaid and/or SNAP. Medicaid pays if usually high medical expenditures are the cause of low resources and SNAP provides benefits if low resources are the result of a low income realization. We set the consumption floor to \$11,600 in 2024 dollars, which is informed by estimates from Moffitt (2020).[19]

2.4 Earnings and Income

Our earnings process is based on data from the 1997-2024 Annual Social and Economic Supplements (ASEC) of the Current Population Survey (CPS) and the 1996-2023 waves of the Panel Study on Income Dyanamics (PSID) . The calibration of our earnings process generates an earnings distribution that is broadly consistent with the data. As Table 3 shows, model earnings are within 5 percent of the data at the 10^{th}, 25^{th}, 75^{th} and 90^{th} percentiles, 10 percent below the data at the median, and about 60 percent of the data at the 99^{th} percentile. Model income is 8 to 27 percent above the data up to the 90^{th} percentile and

[18]The Frisch elasticity for a household in the model is generally positively correlated with a household's wealth, average earnings history and health state (worse health means a higher Frisch elasticity) and negatively correlated with a household's age, productivity, and medical expenditures.

[19]Moffitt (2020) estimates the average benefits that non-elderly and non-disabled SNAP families receive from different sources, including the Child Tax Credit (CTC), Supplemental Security Income (SSI), subsidized housing, Special Supplemental Nutrition Program for Women, Infants, and Children (WIC), Temporary Assistance for Needy Families (TANF), and Unemployment Insurance (UI). Estimates of consumption floors from other authors include: Hubbard et al. (1994) use \$21,100, Scholz et al. (2006) use \$18,200, De Nardi and Yang (2014) use \$16,400, Ozkan (2013) uses \$13,200, Moffitt (2020) calculates \$11,600, French and Jones (2011) uses \$8,500, and De Nardi et al. (2010) use \$5,400 (all numbers adjusted to 2024 dollars using the CPI-U).

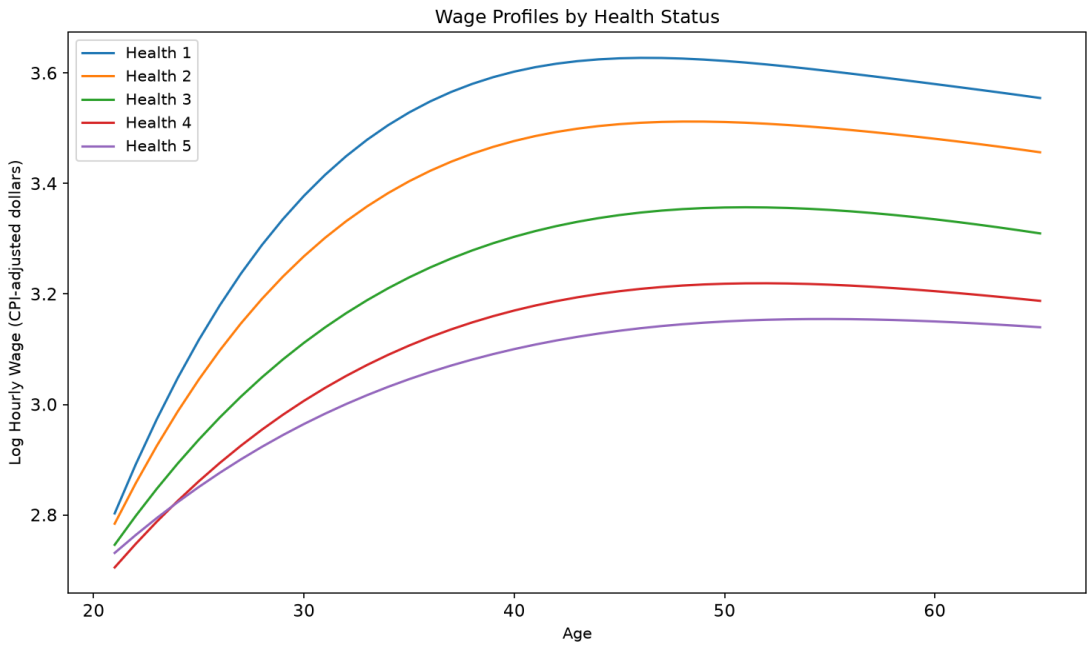


Figure 2: Earnings Potential by Age and Health Status

Sources: ASEC 1997-2024 and Penn Wharton Budget Model.

about 70 percent of the data at the 99$^{\text{th}}$ percentile. The model is less successful at matching wealth, which falls short of the data at every percentile except the 75$^{\text{th}}$ and especially at the 99$^{\text{th}}$ percentile, and as a result, is also unable to match the income distribution at the very top of the distribution.[20]

Hourly wages in the economy are the product of the efficiency wage w_t and labor productivity $e(j, h, z)$, which depends on age, health state and a persistent productivity shock. We set TFP, $A = 0.845$ to normalize the efficiency wage in the initial steady state to $w_{T_0} = 1$. The working ability $e(j, h, z)$ of an age-j household in health state h with productivity shock z satisfies

$$\ln e(j, h, z) = \ln \bar{e}(j, h) + \ln z$$

for $j = 21, \ldots, 64$, where $\bar{e}(j, h)$ is the average working ability at age j for somebody who

[20]Typically, these kinds of models are unable to generate the amount of wealth at the very top of the distribution because the only savings motive is precautionary. Other model features not related to health are required to make the model more successful at matching the top of the wealth distribution. See Cagetti and De Nardi (2008) for a discussion of the kinds of models that could accomplish that.

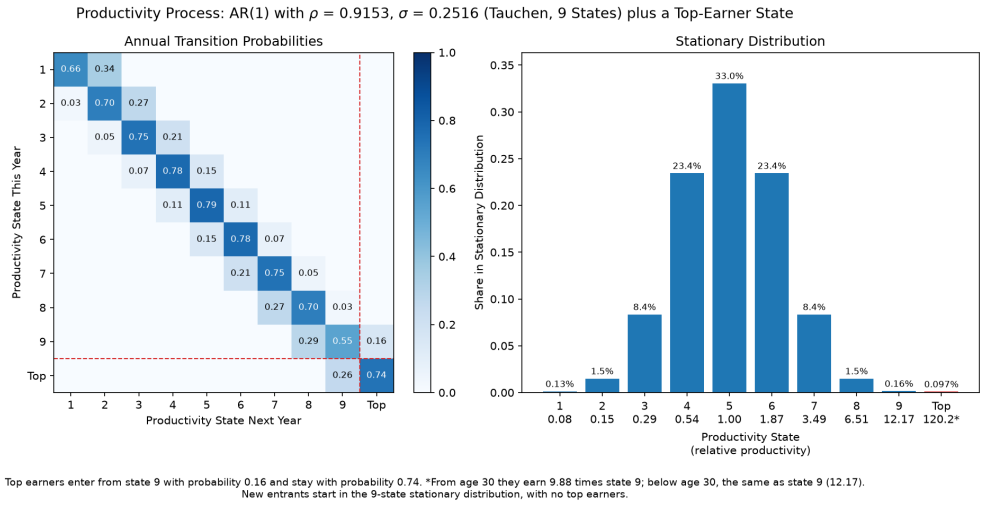


Figure 3: Earnings Shock Process: Annual Transition Probabilities and Stationary Distribution

Sources: PSID 1996-2023 and Penn Wharton Budget Model.

is in health state h, and z is the persistent shock that follows an AR(1) process,

$$\ln z' = \rho \ln z + \epsilon_z$$

for $j = 21, \ldots, 64$. The shock, ϵ_z, is normally distributed, $\epsilon_z \sim N(0, \sigma_z^2)$. Households enter the model at age 21 with z drawn from the stationary distribution of the discretized process described below.

We assume average earnings potential, $\bar{e}(j, h)$, follows the specification

$$\ln \bar{e}(j, h) = \alpha^e + \sum_{i=1}^{4} \beta_{i,h}^e \; j^i \tag{76}$$

for ages $j = 21, ..., 64$ and include year fixed effects. We use individual-level earnings per hour (total wage income divided by total hours worked). For the ASEC, we use only individuals working in the private sector. The profile of average earnings potential by age and health is estimated by ordinary least squares regression. We estimate the same specification using both the PSID and the ASEC data. Figure 2 shows the estimated values from the ASEC data, which are the ones we calibrate the model with.

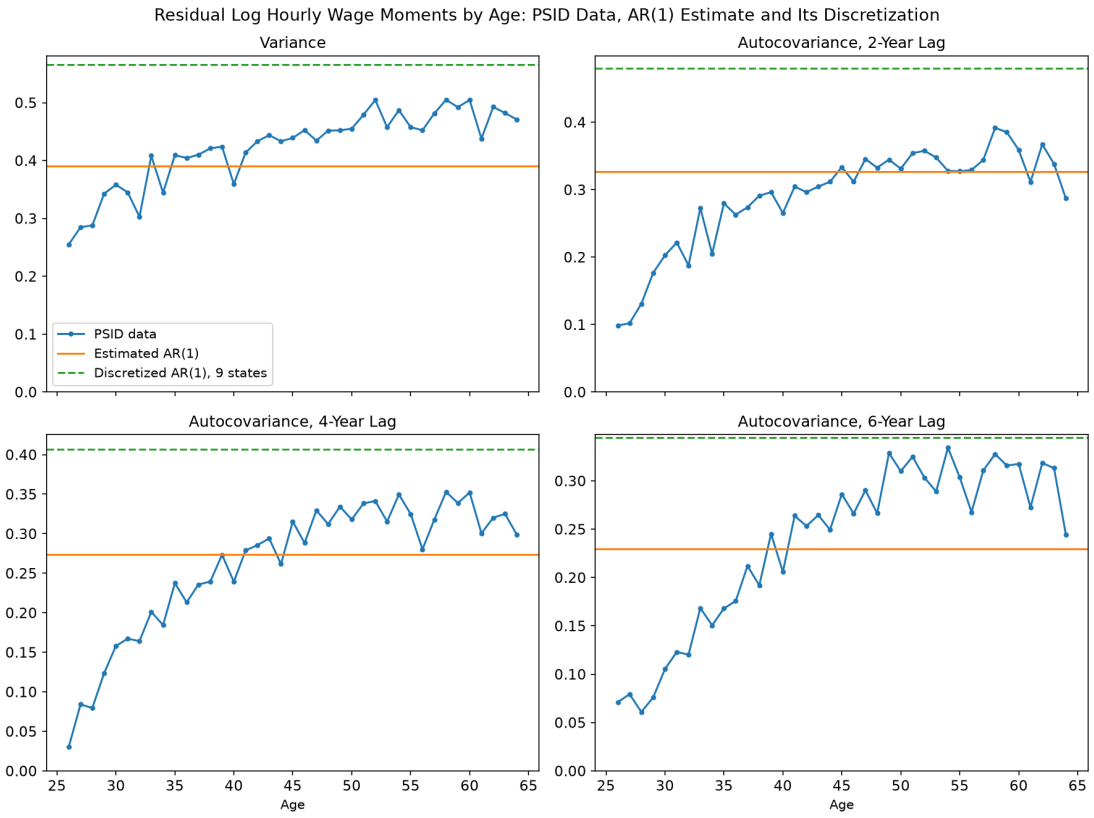


Figure 4: Residual Log Hourly Wage Moments by Age: Data, Estimated AR(1) and Its Discretization

Note: Horizontal lines are the stationary moments of the estimated AR(1) process and of its nine-state discretization.
Sources: PSID 1996-2023 and Penn Wharton Budget Model.

From age 25, average earnings potential falls with each step down in health status. Below age 25, earnings potential in health state 5 is slightly above that in health state 4.

We estimate ρ and σ_z using the PSID by first estimating the same specification as in (76), extracting the residuals, and then using two-step GMM to fit the variance and the 2-, 4- and 6-year autocovariances of the residuals. We pool all ages from 21 to 64, so ρ and σ_z do not vary with age, and, as in the OLG model, the estimated process has no transitory shock. The annual estimates are $\rho = 0.9153$ and $\sigma_z = 0.2516$. Figure 4 compares the moments in the data, by age, with the stationary moments of the estimated process and of its discretization.

The log-persistent shock is discretized into nine nodes using the method of Tauchen

Table 3: Earnings, Income, and Wealth Distributions, Model versus Data

	Percentile of Distribution					
	0.10	0.25	0.50	0.75	0.90	0.99
Earnings						
Model	22.6	41.5	72.2	139.9	239.1	650.0
Data	21.6	43.2	80.0	140.5	250.8	1,091.7
Income						
Model	27.4	48.7	87.6	170.5	276.5	788.8
Data	21.6	43.2	80.0	140.5	256.2	1,149.0
Wealth						
Model	0.0	13.2	165.2	650.7	1,327.5	4,943.6
Data	0.6	26.3	168.9	584.4	1,669.3	29,295.6

Notes: In thousands of U.S. dollars. Data samples are households with head of household under 65 and at least one adult in the labor force. Data from 2022 converted to 2024 dollars using the CPI-U from December 2021 and December 2024.
Source: 2022 Survey of Consumer Finances.

(1986), with the grid spanning four standard deviations of the stationary distribution on either side of zero. We then add a 10th point into the earnings process to better capture earnings and wealth at the very top of the distribution. Only households at the 9th point can move to the 10th point, which they do with probability 0.16. Households at the 10th point stay there with probability 0.74, following Guvenen et al. (2021), and otherwise return to the 9th point. From age 30, productivity at the 10th point is a multiple of productivity at the 9th point, which we calibrate to match the top 1 percent share of earnings in the 2022 Survey of Consumer Finances (14.8 percent); the calibrated multiple is 9.88. Below age 30, the 10th point has the same productivity as the 9th point. New entrants never start at the 10th point. Figure 3 shows the resulting transition probabilities and stationary distribution.

The average labor-income of working-age households was $124,131 in 2024, according to the 2024 Annual Social and Economic Supplement (ASEC) of the Current Population Survey (CPS). We set the dollars per model unit so that average labor income in the baseline economy matches that value, which implies that one model unit is approximately

equal to $141,710 in 2024 growth-adjusted dollars. The model uses that ratio to convert some policy variables into model units.

The calibration of our earnings process generates aggregate earnings, income, and wealth distributions that are broadly consistent with the data. As is typical for these models, we cannot generate the amount of wealth at the very top of the distribution, which would require other model features not related to health.[21] However, model earnings are within about 10 percent of the data up to the 90th percentile.

2.5 Inheritances

In the model, households have no bequest motive and place no value on the assets they leave when dying, so all bequests are accidental. The value of death, ζ (calibrated in Section 2.6), does not depend on those assets. Some of the assets left at death are used to pay for estate costs and some of it may be taxed. The transactions cost function follows Feiveson and Sabelhaus (2018b):

$$\Xi(a') = 0.5 \times \max\{0, a' - \$10{,}000\}$$

while tax policy determines the tax function $\tau_{E,t}$.

We distribute inheritances Q according to empirical age and income profiles derived from the 2001-2019 waves of the Survey of Consumer Finances (SCF). That distribution is represented by the PDF $\omega^q(j, z)$ (see Equation 9).[22] The model generates an inheritances-to-GDP ratio of 2.1 percent in the initial steady state, which is within the range of estimates provided by Feiveson and Sabelhaus (2018a) (1.5 percent), Hendricks (2002) (2.0 percent), and Gale and Scholz (1994) (2.6 percent).

[21] See Cagetti and De Nardi (2008) for a discussion of the economic models that can explain the high concentration of wealth at the very top.

[22] For more information see https://budgetmodel.wharton.upenn.edu/issues/2021/7/16/inheritances-by-age-and-income-group.

2.6 Health

2.6.1 Average Medical Spending by Age

We estimate total medical expenditures using MEPS data for the 2010-2022 period for the 21–84 year old population, controlling for age and health state.[23] For each age and health state, we calculate the average medical expenses for three bins, corresponding to the bottom 40 percent ($d = 1$), the middle 50 percent ($d = 2$), and the top 10 percent ($d = 3$). For those 85 to 100 years old, we extend each of these series with a linear age trend fitted to ages 21 to 84. We then smooth each series over the full 21 to 100 age range by fitting a cubic polynomial in age. Figure 5 shows the resulting total household medical expenditures by age and health state of the head of household, estimated for 21-84 year olds and projected for 85-100 year olds.

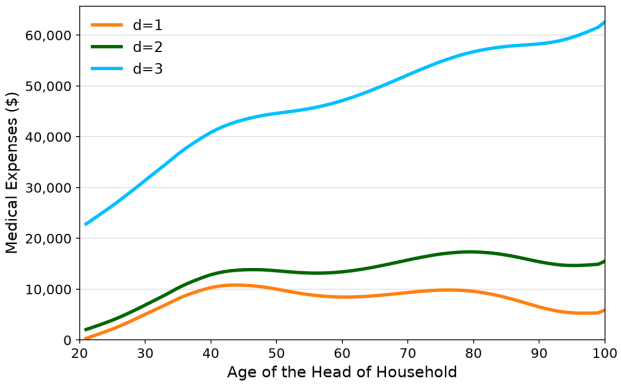
MEPS reports less spending than the National Health Expenditure Accounts (NHEA), both because the NHEA includes services, payments, and populations that MEPS does not cover and because MEPS respondents underreport their care. We therefore scale MEPS spending to 2024 NHEA personal health care spending restated on the MEPS scope. Matching aggregate spending matters in our model because medical spending determines Medicare and Medicaid outlays and thus government budgets, sets private insurance premiums through the insurers' zero-profit condition, and shapes the out-of-pocket risk that drives households' saving and insurance decisions. Scaling is justified because the shortfall on the MEPS scope reflects measurement error rather than care that is not provided: Bernard et al. (2018) find that MEPS spending falls short of the NHEA even for the same services and population, and restricting the target to that scope means this adjustment adds no spending on services or populations the model does not represent. Following the 2012 reconciliation of Bernard et al. (2018), we remove services outside MEPS (mainly nursing homes, other residential and personal care, and non-durable medical products),

[23] The publicly available MEPS data groups all data for those above age 85 into the category for 85 year olds.

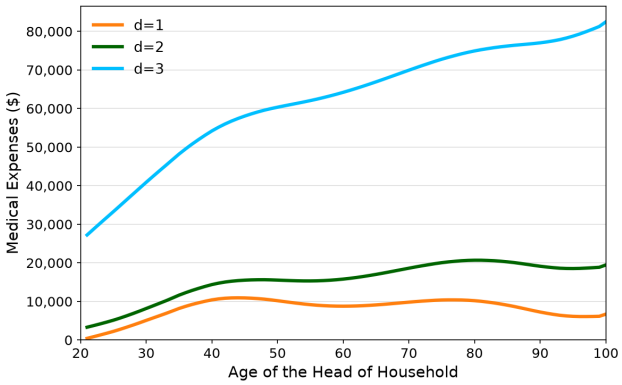
payments not tied to patient care, and spending on the institutionalized population, active-duty military, and foreign visitors, and allocate the remainder to age groups and payers using the 2018 NHEA age tables. The resulting target of $3,280 billion is 73 percent of 2024 personal health care spending. Since the MEPS shortfall differs by payer, from 9 percent for out-of-pocket spending to 35 percent for Medicaid in 2012, we scale each person's spending separately by payer so that average spending per person matches the target in each age group and payer. The resulting adjustment factors, which also capture real growth in spending since the sample years, vary mainly with age, from about 1.1 at ages 65 to 84 to as much as 1.8 at ages 19 to 44, and differ little across the three expenditure bins. Because the target excludes spending outside the MEPS scope, aggregate model spending remains below total NHEA spending, and we close that remaining gap by scaling aggregate private insurance, Medicare and Medicaid outlays (Section 2.6.10).

Let $m^H(j, h, d)$ represent the total medical expenses for a head of household of age j, health state h, and expenditure bin d, as derived from the MEPS data. We assume that spouses incur average health expenditures based on the head's age j, while all children incur a fixed average expenditure m^C. Accordingly, spousal medical expenses are defined as $m^S(j) = \mathbb{E}[m^H|j]$, where $\mathbb{E}$ uses the model's probability distribution. Total household medical expenditures are then calculated as:

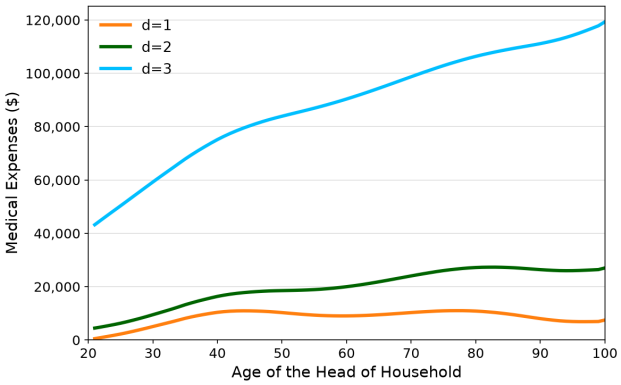
$$m(j, h, d) = m^H(j, h, d) + (\Omega_{a,T_0}(j) - 1)m^S(j) + \Omega_{c,T_0}(j)m^C.$$



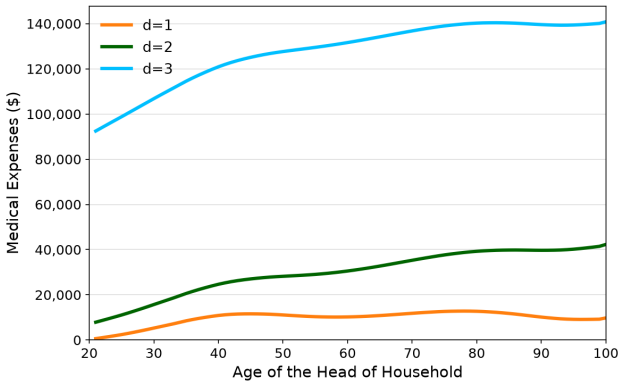
(a) Health State 1



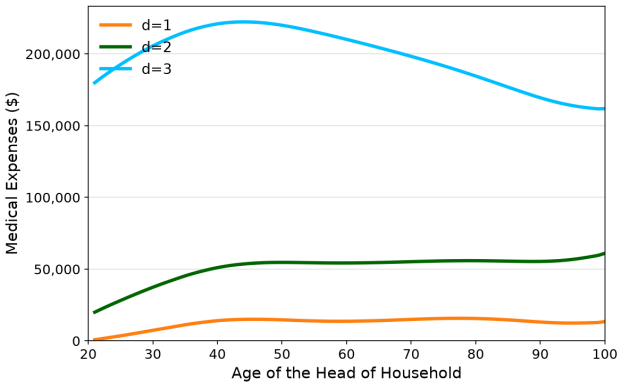
(b) Health State 2



(c) Health State 3



(d) Health State 4



(e) Health State 5

Figure 5: Total Health Expenditures by Age and Health State

Source: Penn Wharton Budget Model estimates from the Medical Expenditure Panel Surveys for 2011-2022 CPI-U adjusted to 2024dollars.

Table 4: Average Individual Medical Expenditures by Age

Age of Head	Model	Data
21-25	$4,580	$5,550
26-34	$5,970	$6,690
35-44	$7,800	$8,640
45-54	$10,720	$11,220
55-64	$14,050	$14,120
65-74	$17,200	$17,240
75-84	$20,260	$20,270
21-64	$8,840	$9,440
65+	$18,790	$18,880
21+	$11,360	$11,830

Notes: Spending of the household head. Data: the model's input medical spending (MEPS, scaled to the National Health Expenditure Accounts) by age, health status and spending level, averaged over the initial steady state's households. Model: the same households' spending in the initial steady state, with forgone care counted as zero. All dollar values are adjusted to 2024 dollars and rounded to the nearest $10.
Source: MEPS data for 2010-2022.

Table 4 shows average individual medical expenses by age groups and compares those to the MEPS data the model takes as input. Model spending counts forgone care as zero, so it is below the data in every age group. The gap narrows with age, from about 17 percent at ages 21 to 25 to less than 1 percent from age 55. Model spending is about 6 percent below the MEPS for ages 21 to 64, less than 1 percent below for ages 65 and older, and about 4 percent below for all adults age 21 and older. Households with health insurance only pay a fraction of the amounts shown out-of-pocket.

We restrict the value of death, ζ, to be sufficiently negative,[24] and calibrate the parameter ζ so that the initial steady state matches the ratio of average paid medical care of uninsured households aged 26 to 64 in health state 5 to that of privately insured households of

[24] $u()$ is strictly negative, so the value of living is negative as well, and we need ζ to be sufficiently negative to ensure that households prefer living to death. Hall and Jones (2007), for example, solve that problem by adding a constant to the per-period utility function to ensure that it is a positive number (see their Equation (6) on page 47). We take a different approach here and do not change the standard utility function.

the same ages and health state (see Table 7):

$$R_5 = \frac{\int_{S_U} \iota(s)\, m(j,h,d)\, dX_{T_0}(s) \Big/ \int_{S_U} dX_{T_0}(s)}{\int_{S_P} \iota(s)\, m(j,h,d)\, dX_{T_0}(s) \Big/ \int_{S_P} dX_{T_0}(s)}, \tag{77}$$

where $\iota(s)$ is the household's care decision, so that spending counts only when the household pays for care. The set S_U contains households aged 26 to 64 in health state 5 who are uninsured ($i = 0$) and not categorically eligible for Medicaid. The set S_P contains households aged 26 to 64 in health state 5 who are privately insured, excluding Medicare enrollees and households categorically eligible for Medicaid. Appendix A describes how we update ζ to match this ratio.

2.6.2 Out-of-Pocket Spending

We use MEPS data to estimate the fraction of total medical expenses a person pays as OOP expenses for each insurance type, or $\gamma^{oop}(m,i)$. We focus on households that received insurance coverage from a single source to ensure that we capture the proper HI reimbursement policy. We find that Medicaid is the most generous with required OOP shares generally below 6 percent, and that Medicare is more generous than Private Health Insurance at every level of spending, by the widest margin for the smallest claims. Equation (3) combines these per-person fractions into a household's out-of-pocket share.

For each insurance product i, we estimate the out-of-pocket share function $\gamma^{oop}(m,i)$ using a third-order polynomial. Specifically, we assume:

$$\gamma^{oop}(m,i) = \sum_{j=0}^{3} \left[(\log(m/100))^j \times \text{inscoef}_i(j) \right]$$

where the vector inscoef_i contains four parameters estimated via Ordinary Least Squares (OLS). These parameters are obtained by fitting the polynomial to MEPS data on out-of-pocket expenditure shares across the distribution of total medical expenses.

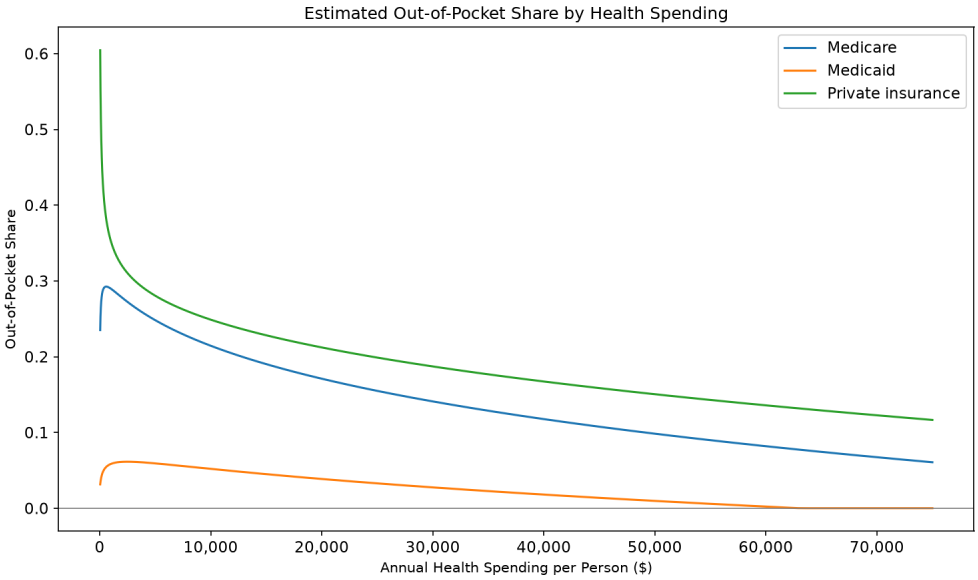


Figure 6: Estimated OOP shares by total medical expenditures and insurance plan

Source: PWBM estimates from the Medical Expenditure Panel Survey.

The results are shown in Figure 6.

2.6.3 Excess Cost Growth

To parameterize the annual excess cost growth rates, v_t^m for the three different insurance types, we rely on estimates by Congressional Budget Office (2018), which are summarized in Table 5. Over the 2025-2055 period, excess cost growth in private health insurance cumulates to 56.3 percent, 8.9 percentage points more than in Medicaid (47.4 percent), and 16.9 percentage points more than Medicare (39.4 percent).

Note in any steady-state, all excess cost growth rates are set to 1.

2.6.4 Health Transition and Survival Probabilities, and Forgone Treatment

We estimate health transition probabilities, $\pi_h[h'|j,h,d,\iota = 1]$, and survival probabilities, $\delta_{j,h}^{\text{MEPS}}$, from MEPS data (ages 21 to 60) and HRS data (ages 55 and older). MEPS follows respondents over two consecutive years and therefore records one-year transitions, while HRS interviews respondents every two years. We convert the HRS two-year tran-

Table 5: Excess Cost Growth By Insurance Provider

Year	Private Insurance	Medicaid	Medicare
2025	2.0	1.4	1.0
2030	1.9	1.6	1.2
2035	1.7	1.4	1.1
2040	1.4	1.3	1.1
2045	1.2	1.1	1.0
2050	1.0	1.0	1.0
2055	1.0	1.0	1.0
2025-55	56.3	47.4	39.4

Notes: The 2025-55 total shows the cumulative excess cost growth over that period. Excess cost growth after 2055 is assumed to be 1 percent until it is set to zero starting in 2061.
Source: Congressional Budget Office (2018)

sition matrices into one-year matrices by taking a matrix square root, constrained so that every one-year probability is nonnegative and each row sums to one. Each survey comes with its own survey weights. To put them on a common scale, we multiply every HRS weight by a single factor: the sum of MEPS weights divided by the sum of HRS weights over the overlapping ages 55 to 60. For each survey, age, and current health state, we then compute the weighted shares of respondents who move to each health state or die. Between ages 55 and 60, we average the shares of the two surveys, weighting each survey by its total survey weight among respondents of that age and current health state. Below age 55, the shares come from MEPS only, and above age 60 from HRS only. We estimate health next year, h', among survivors with a multinomial logit, and death before next year with a separate binary logit. Both depend on current health h and a cubic in age j. We estimate both logits on the combined shares, so that each age and current health state enters with the combined survey weight of the respondents it represents. We then multiply the health transition probabilities among survivors by the survival probability. We use the following self-reported health states: 1=excellent, 2=very good, 3=good, 4=fair, and 5=poor. Those estimates are shown in Figure 7.

The Microsim dataset provides forecasts of survival probabilities by age j and year t, denoted $\delta_{j,t}^{\text{microsim}}$. In our model, we assume that survival probabilities also depend on the

household health state h.

To account for this additional heterogeneity, we start from the survival probabilities by age j and health state h estimated above, $\delta^{\text{MEPS}}_{j,h}$.

To construct the survival probabilities used in the model, conditional on age j, health state h, and year t, while endogenously matching the survival rates, $\delta^{\text{microsim}}_{j,t}$, we solve for $\varphi_{j,t}$ using the following equation, which is written in terms of death rates, $1-\delta$:

$$\sum_h \omega_{j,h,t} \left(1-\delta^{\text{MEPS}}_{j,h}\right)^{\varphi_{j,t}} = 1-\delta^{\text{microsim}}_{j,t}, \tag{78}$$

for every age j and year t. Intuitively, equation (78) represents a weighted average of death rates across health states that matches the aggregate death rate obtained from the Microsim dataset.

The weights $\omega_{j,h,t}$ are based on the population distribution over health states:

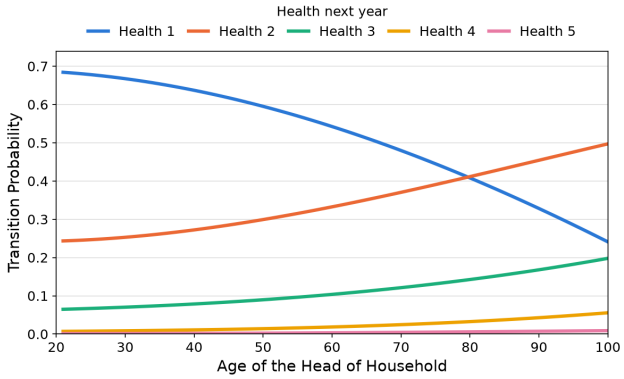
$$\omega_{j,h,t} \equiv \frac{\tilde{x}_t(j,h)}{\hat{x}_t(j)},$$

where $\tilde{x}_t(j,h) = \int_{A\times B\times Z\times D\times I} x(s)ds$ and $\hat{x}_t(j) = \sum_h \tilde{x}_t(j,h)$, so that $\sum_h \omega_{j,h,t} = 1$. These weights ensure that more prevalent health states contribute proportionally to the aggregate survival probability.

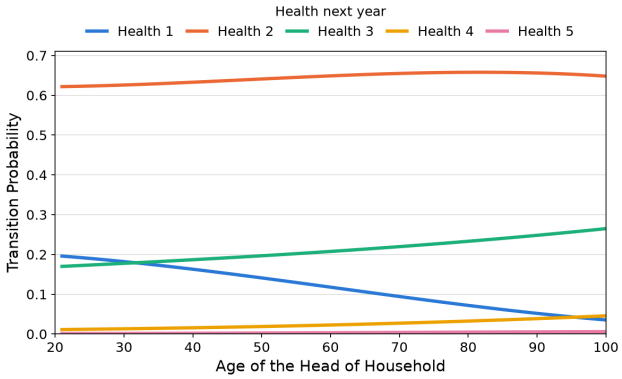
Finally, we define the model survival rates as

$$\delta_t(j,h) = 1-\left(1-\delta^{\text{MEPS}}_{j,h}\right)^{\varphi_{j,t}}. \tag{79}$$

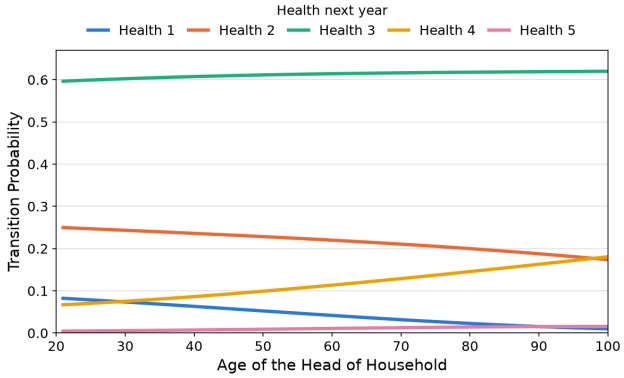
The weights $\omega_{j,h,t}$ are endogenous: they are computed from the model's own distribution of households over health states, X_t, which depends on households' choices and on the survival rates themselves. The exponents $\varphi_{j,t}$ are therefore solved jointly with the distribution, as part of the fixed point calculation. Survival rates are computed in the baseline; policy simulations use the baseline survival rates. Figure 7f shows the resulting survival probabilities in the initial steady state, $\delta_{T_0}(j,h)$.



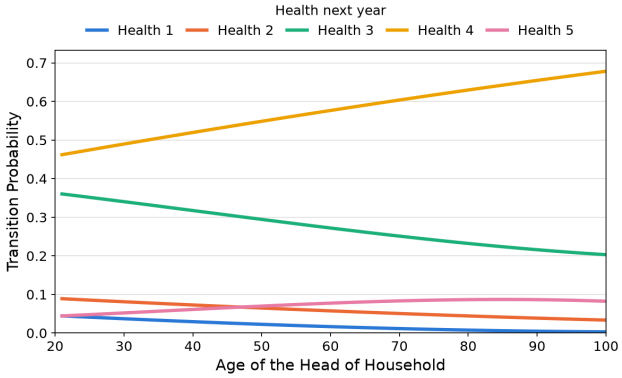
(a) From Health State 1



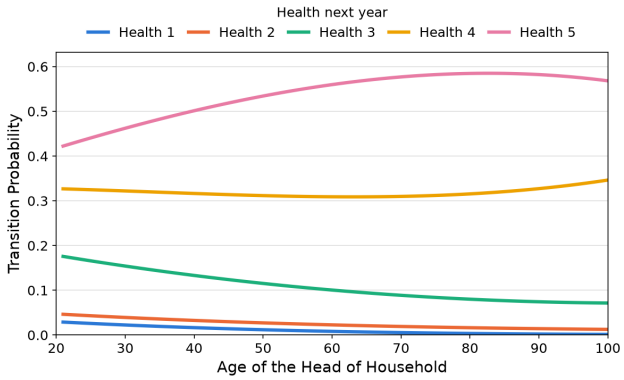
(b) From Health State 2



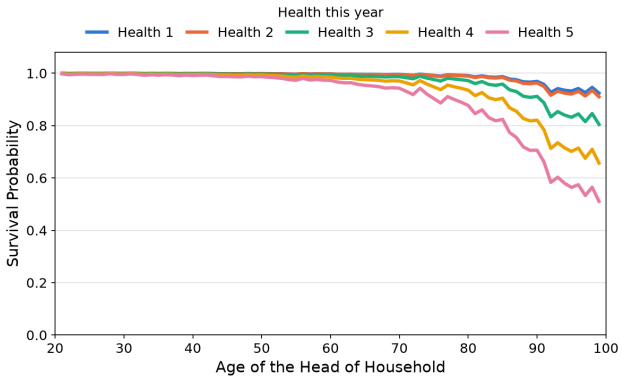
(c) From Health State 3



(d) From Health State 4



(e) From Health State 5



(f) Survival by Age

Figure 7: Estimated health transition and survival probabilities by Age and Health State

Source: Penn Wharton Budget Model estimates from the Medical Expenditure Panel Survey (MEPS; ages 21–60) and the Health and Retirement Study (HRS; ages 55 and older).

Households opting for medical treatment ($\iota = 1$) follow those estimated transition probabilities, while those forgoing treatment ($\iota = 0$) face adjusted probabilities reflecting unmitigated health risks. A primary identification challenge arises because the data does not explicitly label households that experienced a health shock but chose to forgo care. Categorizing all households with zero expenditures as "choosing not to be treated" would introduce significant bias; for many, zero expenditure simply reflects the absence of a health shock rather than a deliberate decision to avoid healthcare.

To resolve this identification problem, we rely on the following key assumptions:

1. **Low health expenditures:** We assume that households in the lowest medical expenditure group ($d = 1$) who forgo treatment face health transitions comparable to those observed among the uninsured population.

2. **Expenditure proxy for severity:** Medical expenditures serve as a signal for unobserved heterogeneity within health states. We assume that the magnitude of the expenditure shock (d) is positively correlated with the severity of the underlying health condition.

3. **The marginal cost of forgone care:** The probability of transitioning to a worse health state is an increasing function of the "avoided" expenditure shock. Consequently, forgoing a larger required medical expenditure results in a higher likelihood of a negative health transition.

To implement these assumptions, we calibrate the transition probabilities for forgoing care, $\pi_h[h'|j, h, d, 0]$, by reweighting the treatment transitions, $\pi_h[h'|j, h, d, 1]$, using the following weighting function:

$$\pi_h[h'|j, h, d, 0] = \frac{\omega^{hp}(h, h', j, m)\pi_h[h'|j, h, d, 1]}{\sum_{h'} \left(\omega^{hp}(h, h', j, m)\pi_h[h'|j, h, d, 1]\right)} \tag{80}$$

Table 6: Estimates of $\gamma^{ht}(h, h')$

h/h'	h'_1	h'_2	h'_3	h'_4	h'_5
h_1	0.942	0.971	1.000	1.029	1.058
h_2	0.929	0.973	1.003	1.033	1.063
h_3	0.912	0.954	1.013	1.045	1.076
h_4	0.829	0.859	0.997	1.142	1.172
h_5	0	0	0	0	1

Notes: The parameters $\gamma^{ht}(h, h')$ determine how forgoing medical care changes a household's health transitions. For a household in current health h (rows) that forgoes care, they reweight the probability of each next-year health state h' (columns), where 1 is excellent and 5 is poor. The entries rise toward poorer health, so forgoing care shifts probability toward worse health states.

where the weights are:

$$\omega^{hp}(h, h', j, m) = \gamma^{ht}(h, h')^{\delta^{ht}(h)\log_2\left(1+\frac{m_{T_0}(j,h,d)}{m_{T_0}(j,h,1)}\right)}, \quad \forall h, h' \in H \tag{81}$$

In this specification, the $h^{max} \times h^{max}$ matrix γ^{ht} determines the direction of redistribution (e.g., from healthy to sick), while the parameters $\delta^{ht}(h)$, in conjunction with the ratio of medical expenditures $\tilde{m}(j, h, d)/\tilde{m}(j, h, 1)$, determine the intensity of that redistribution. For the lowest expenditure group ($d = 1$) the ratio equals one and $\log_2 2 = 1$, so the exponent is $\delta^{ht}(h)$ itself. Higher expenditure groups raise the exponent less than proportionally: a group that spends 20 times as much as the lowest group has an exponent about 4.4 times as large.

We identify $\gamma^{ht}(h, h')$ and $\delta^{ht}(h)$ through a multi-step calibration. First, we estimate $\pi_h[h'|j, h, d, 1]$ for the insured and a separate transition profile, $\pi_h^{unins}[h'|j, h, d, 1]$, for the uninsured. We then estimate $\gamma^{ht}(h, h')$ to minimize the sum of square residuals:

$$\sum(\pi_h[h'|j, h, 1, 0] - \pi_h^{unins}[h'|j, h, 1, 1])^2$$

We subject this minimization to the following structural restrictions:

- **No spontaneous recovery:** $\gamma^{ht}(h, h'') \geq \gamma^{ht}(h, h')\ \forall h'' > h'$. This ensures that forgoing care never increases the probability of transitioning into a better health state

relative to sicker states.

- **Critical shocks:** For households in the second worse health state who receive the highest expenditure shocks, forgoing care results in a transition to the worst health state with certainty: $\pi_h[h^{max}|j, h^{max-1}, 3, 0] = 1$.

- **Absorbing state:** Households in health state h^{max} who forgo care remain in state h^{max} with certainty.

Empirically, the uninsured spend roughly 60 percent less on medical care than the insured.[25] We set $\delta^{ht}(h)$ to match this ratio for each health state, targeting moments from the MEPS data. We calibrate $\delta^{ht}(1), \ldots, \delta^{ht}(4)$ jointly within the initial steady-state calibration (Section 1.8). Each iteration takes a damped quasi-Newton step on the four spending ratios. The step uses a Jacobian estimated by finite differences and revised with Broyden updates. Forgone care in health state 5 leads to health state 5 with certainty, so $\delta^{ht}(5)$ has no effect, and we set it to one. Given the new δ^{ht}, we refit γ^{ht} by least squares on the uninsured transitions of the lowest expenditure group at ages 21 to 64. In that group the weight ω^{hp} equals $\gamma^{ht}(h, h')^{\delta^{ht}(h)}$, so the transitions identify only that power. Rescaling a row of γ^{ht} leaves Equation (80) unchanged, so we normalize rows 1 to 4 to sum to five. The spending ratios also depend on the higher expenditure groups, and they pin down δ^{ht}. Each refit moves γ^{ht} 15 percent of the way toward the least-squares solution, and γ^{ht} stays fixed after the third refit. Table 1 lists the update rules of all internally calibrated parameters. Finally, we set the value of death, $\zeta = -462.81$, to match the average ratio of medical spending between uninsured and privately insured households aged 26 to 64 in poor health ($h = 5$).

Table 6 shows the resulting estimates for γ^{ht}, and Table 7 shows that our model matches the data for the ratio of medical spending of the uninsured to the insured in each health

[25] In fact, based on data from the National Health Interview Survey, the uninsured are more than four times as likely as the insured to forgo or delay needed medical treatment as a result of costs. See National Center for Health Statistics (2018).

Table 7: Calibration of the ratio of medical spending of the uninsured to the insured

	Health State					
	1	2	3	4	5	Total
Model	49	44	37	33	39	39
Data	49	44	37	34	38	42
$\delta(h)$	14.53	15.72	8.65	0.96	1.00	
ζ						-462.81

Notes: Model and Data for the medical spending ratio of the uninsured to the insured expressed as percentages. The parameters $\delta(h)$ depend on health state h, while the parameter ζ is the same across all health states. Those parameters are set such that the spending ratios of the uninsured to the insured in the model match those in the data.
Source: Data from the Medical Expenditure Panel Survey for working-age households 2012-2022.

state very well.

We assume that households' health investment choices do not affect their survival probabilities directly, only through their effects of moving to a worse health state. However, a bigger likelihood of transitioning into worse health also decreases households' life expectancy, because those in lower health states have lower survival rates.

Table 10 shows that our approach generates a distribution of health status in the population that matches the data well, particularly for working-age households.

Our approach to modeling health departs from the seminal human capital framework of Grossman (1972). While Grossman treats health as a capital stock that depreciates deterministically and grows through discretionary investment, we model health as a stochastic process governed by a household's current health state, age, and the decision to obtain medical treatment. This distinction allows our framework to capture the fundamental uncertainty inherent in health shocks that a deterministic capital-accumulation model may overlook. In this setting, households that forgo medical treatment face a higher probability of transitioning into sicker health states in subsequent periods. These transitions carry significant economic consequences, including increased mortality risk, diminished labor productivity through lower wages, and higher future medical liabilities.

Our framework offers several distinct advantages over the Grossman model by grounding the simulation in empirical health states. We match health states directly to observed health expenditures, transition probabilities, and mortality rates, whereas the Grossman model often treats health spending as discretionary and frequently fails to link that spending directly to mortality outcomes. By tying health transitions to mortality, we avoid the pitfall noted by Ehrlich and Chuma (1990), who observe that the Grossman model struggles to generate realistic life-cycle mortality patterns because households can theoretically invest indefinitely to forestall death. Our model ensures that biological aging and stochastic shocks eventually dominate, regardless of investment levels. Furthermore, we relax the direct coupling between spending and health improvement. While the basic Grossman model implies that higher spending necessarily yields better health, empirical evidence from Bajari et al. (2014), Khwaja (2010), and Card et al. (2009) suggests a more subtle relationship. Our framework acknowledges that medical spending often addresses the severity of a shock rather than simply purchasing health increments, thereby forcing households to face realistic trade-offs between current consumption and health maintenance.

The theoretical and empirical limitations of treating health strictly as a depreciating asset inform our shift toward a stochastic specification. Ehrlich and Chuma (1990) highlight that Grossman's assumption of a constant-returns-to-scale health production function introduces indeterminacy regarding optimal investment choices, which defies a systematic resolution of the choice of both optimal health paths and longevity. Similarly, Hall and Jones (2007) and Grossman (2000) discuss the difficulty of reconciling the capital-stock approach with observed longevity choices. In the basic Grossman model, population health also relates directly to out-of-pocket expenses; if these were set to zero, households would theoretically consume all available healthcare services to maximize their health stock. Empirically, the implications of the Grossman model have yielded mixed results at best, as noted in the micro- and macro-based reviews by Zweifel (2012) and Hartwig et al.

(2018). By shifting the focus to stochastic transitions conditioned on treatment, we provide a framework more consistent with the observed volatility in medical expenditures and the persistence of health states.

2.6.5 Administrative and Overhead Spending

Health insurance administrative and overhead spending varies between payers and typically includes spending on advertising, utilization management (including programs to combat fraud and abuse), claims and payment processing, profits, and taxes and fees.[26] Including an estimate for administrative spending is important, because it directly increases private health insurance premiums and the cost of providing public health insurance programs.

Private health insurance companies spend the most on administrative and overhead costs, with estimates ranging from 11 percent in the large-group market, 16 percent in the small-group market, to 20 percent in the nongroup market.[27] In a more recent study, CBO estimated total administrative expenses of ESI to be 12 percent, which is the value we use for all private insurance.[28]

Medicare generally has the lowest administrative costs. According to the Medicare Trustees, Medicare fee-for-service (FFS) spends about 1.4 percent on administrative costs,[29] while CBO estimates that number to be 2 percent. Including Medicare Advantage (Medicare Part C) and Medicare Part D plans, which are operated by private insurance companies, CBO estimates that total Medicare administrative costs are 8 percent. Data reported in the NHEA suggest that the total administrative costs for Medicare are about 6.9 percent

[26] Note that these estimate ignore large administrative costs born by providers. For a more complete account of administrative costs, see, for example, Woolhandler et al. (2003) and Woolhandler and Himmelstein (2017).

[27] See Congressional Budget Office (2016).

[28] See Congressional Budget Office (2020a). That number is also consistent with the 12 percent administrative spending in private health insurance reported in the 2024 National Health Expenditure Account (NHEA). See National Health Expenditure Accounts, https://www.cms.gov/files/zip/national-health-expenditures-type-service-source-funds-cy-1960-2024.zip

[29] See The Boards of Trustees, Federal Hospital Insurance and Federal Supplementary Medical Insurance Trust Funds (2020).

in 2024. Administrative costs of Medicaid are roughly in line with those of total Medicare. CBO estimates that administrative spending on Medicaid and Chip is 8 percent, while NHEA data suggests that it is 10.4 percent in 2024.[30] We use CBO's estimates for administrative spending, which are summarized in Table 8.[31]

Table 8: Administrative Expenses by Insurer

Insurer	CBO	NHEA
Private Insurance	12.0	12.0
Medicare fee-for-service	2.0	
Total Medicare	8.0	6.9
Medicaid	8.0	10.4

Notes: Data expressed as a percent of total health expenditures. Total Medicare includes the fee-for-service program, Medicare Advantage, and Medicare Part D plans. Medicaid includes Medicaid and CHIP.
Sources: Congressional Budget Office (2020a) and 2024 data from the National Health Expenditure Account.

2.6.6 Medicare and Medicaid Premiums

While Medicare Part A is partially financed through Hospital Insurance (HI) payroll taxes, Medicare Part B (medical insurance) and Part D (prescription drug coverage) are partially financed through income-based premiums. We assume that all retirees enroll in Medicare Parts B and D, which is largely consistent with the data and require households to pay the income-based premiums for those programs.[32] Premiums for Medicare Part B are paid to the government. Total Medicare Part D premiums consist of two parts: a plan premium that is paid directly to the chosen prescription drug insurance plan, and an income based portion that is paid to the federal government. We use the 2024 statutory

[30]The Centers for Medicare & Medicaid Services report average Medicaid administrative costs for 2018 of 4.6 percent, while the NHEA estimates Medicaid administrative costs are 12.2 percent without CHIP. See, https://www.medicaid.gov/state-overviews/scorecard/annual-medicaid-chip-expenditures/index.html (accessed October 28, 2021).

[31]Recent work by Scheinker et al. (2021) find that billing and insurance related costs in the U.S. could be decreased by between 30 and 60 percent.

[32]In 2023, the large majority of Medicare beneficiaries were enrolled in Medicare Parts B (91 percent) and D (78 percent). See CMS Program Statistics, Tab MDCR ENROLL AB 3_CPS_02ENR and Tab MDCR UTLZN D 2_CPS_12UPD.

premiums, which we show in Table 9.

Table 9: 2024 Annual Medicare Part B and D Premiums

Income Threshold	Part B	Part D
$y_t^T \leq \$103{,}000$	\$2,096.40	\$0.00
$\$103{,}000 < y_t^T \leq \$129{,}000$	\$2,935.20	\$154.80
$\$129{,}000 < y_t^T \leq \$161{,}000$	\$4,192.80	\$399.60
$\$161{,}000 < y_t^T \leq \$193{,}000$	\$5,450.40	\$645.60
$\$193{,}000 < y_t^T \leq \$500{,}000$	\$6,708.00	\$890.40
$y_t^T > \$500{,}000$	\$7,128.00	\$972.00

Notes: y_t^T is taxable income. Amounts are per person. Income threshold is for individual tax filers. The average Part D plan premium is \$42.00/month × 12 = \$504.00/year.
Sources: Medicare.gov, available at https://www.medicare.gov/your-medicare-costs/part-b-costs. Archived 2024 data available in the Federal Register (for Part B premiums) and https://www.medicare.gov/drug-coverage-part-d/costs-for-medicare-drug-coverage/monthly-premium-for-drug-plans (for Part D premiums); Average Part D premium available at Kaiser Family Foundation, available at https://www.kff.org/report-section/medicare-part-d-a-first-look-at-prescription-drug-plans-in-2020-issue-brief/

Consistent with current law, Medicaid does not charge insurance premiums.[33]

Our model of health transition and survival generates an aggregate population distribution across health states that matches the data quite well, as Table 10 shows.

Table 10: Distribution by Age and Health State

	Health State									
	1	2	3	4	5	1	2	3	4	5
	Working Age (21-64)					**Retirees (65+)**				
Model	22	37	30	9	2	8	35	35	18	4
Data	25	35	27	10	3	18	31	31	15	5

Notes: The values represent the percentage distribution across health states within each age group.
Source: 2024 MEPS data.

[33]Under current law, the federal government generally prohibits states from charging premiums to Medicaid enrollees with income below 150 percent of the federal poverty line and limits the extend to which states can charge premiums and co-payments. See Guth et al. (2021).

Table 11: Health Insurance Enrollment by Age Group

	Uninsured		Medicaid		ACA	
	Model	Data	Model	Data	Model	Data
21-25	13.8	14.1	18.0	18.3	13.0	3.2
26-34	12.5	12.5	17.5	17.6	0.4	3.4
35-44	11.6	11.6	15.4	15.4	0.8	3.5
45-54	9.2	9.2	13.2	13.2	3.8	2.9
55-64	7.9	7.9	15.0	15.0	9.4	4.2
21-64	10.9	10.8	15.7	15.7	4.9	3.5
26-64	10.4	10.3	15.3	15.3	3.5	3.5

Notes: Data show percentages of the population. Model data from 2024 initial steady state.
Source: Data for 2024 from 2025 CPS.

2.6.7 Health Insurance Enrollment

Our calibration strategy produces a distribution of health insurance enrollment, both in aggregate and by age group, that is consistent with data from the 2025 Current Population Survey (CPS). Table 11 shows that our model closely matches the data for the fraction that is uninsured and enrolled in Medicaid. Our model matches the age distribution of those receiving ACA premium support less well. It overstates enrollment of 21-25 year olds by about 10 percentage points; under current law, that group is able to stay on their parent's insurance plan, a feature we do not model. It also overstates enrollment of 45-64 year olds and understates enrollment of 26-44 year olds. However, we still match the aggregate fraction of 26 to 64 year olds receiving premium subsidies.

We first assume that everybody who qualifies for Medicare and Medicaid enrolls in those programs. We then set a schedule, by age, of assets that are excluded from Medicaid countable assets to calibrate to the Medicaid enrollment by age group we observe in the data. Next we choose the earnings cutoff $\underline{y}^{ESI}$, one of the conditions for an ESI offer (Section 1.1.5.2), to match the aggregate uninsurance rate for working age households and set the age-based weights ω_j^{HI} from Equation 27 such that the uninsurance rate by age group in the model matches the data. Finally, we choose cut-off earnings for below

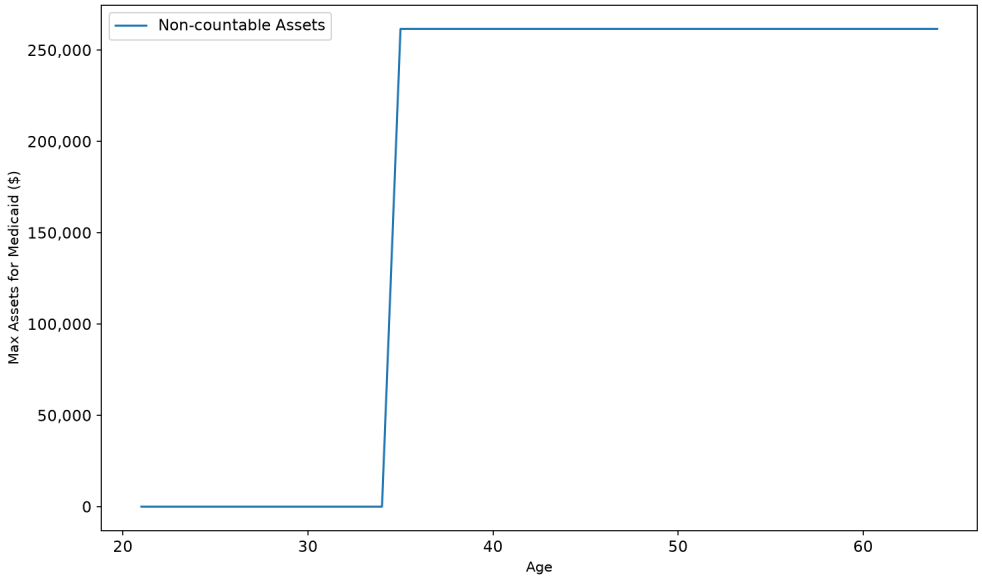


Figure 8: Assets that are excluded from the Medicaid asset test in Model for 2024 initial steady state

Notes: A household passes the Medicaid asset test if its assets in excess of the excluded amount do not exceed $2,000. The excluded amount is calibrated by age to match Medicaid enrollment by age group (Table 11) and is restricted to points on the model's wealth grid.

which households qualify for premium subsidies in the ACA in order to match data on ACA enrollment of working age households.[34]

All retirees are assumed to enroll in Medicare Parts A, B, and D and pay the associated Medicare premiums as shown in Table 9.

Households may qualify for Medicaid categorically if they have low income and low assets. Those with low income but larger assets may qualify medically if their healthcare expenses exceed their total resources.[35] To qualify households must earn less than 138

[34]For our calibration, we target the population of 26 to 64 year olds, because the ACA introduced a rule by which young adults up to age 26 may receive health insurance coverage through their parent's ESI. That makes it difficult to exactly match the enrollment data for the 21-25 year old group. However, we do report enrollment numbers for that age group.

[35]Medicaid eligibility requirements are too complex to model in detail here. Our approach captures the idea that Medicaid insured the low-income households with the greatest need. Mitchell et al. (2021) provide a detail description of the Medicaid program, including a comprehensive discussion of the many different eligibility pathways. According to Congressional Budget Office (2020b), roughly 17 percent of the uninsured in 2019 could enroll in Medicaid but do not. The Congressional Budget Office cites unawareness of households' eligibility or the complexity of the enrollment process that may prevent the eligible uninsured from applying for new coverage or renew their coverage. In addition, the Congressional Budget Office notes, recent immigrants may be discouraged from applying for Medicaid coverage for their citizen children

percent of the federal poverty level (FPL) and own no more than $2,000 in assets, excluding non-countable assets such as a primary residence, a car, personal effects, household goods and furnishings. We adjust the amount of non-countable assets by age to match the Medicaid enrollment rates in the data by age group (see Figure 8 for those parameters). As Table 11 shows, this approach generates Medicaid enrollment that is consistent with the data. In our model, 15.7 percent of 21 to 64 year olds are enrolled in Medicaid compared to 15.7 percent in the data.

We calibrate our model to match an uninsured rate of the 26 to 64 year old population of 10.3 percent (see Table 11). That requires setting the ESI earnings cutoff to $\underline{y}^{ESI} = \$59,752$ and results in an uninsured rate of 10.4 percent in the model.

We set the employer's share of ESI insurance premiums, $\eta^{ESI} = 0.7749$.

To calibrate the model to match the fraction of households without health insurance by age group, we set the weight ω_j^{HI} from Equation 27 by minimizing the sum of squares residuals of the difference between the rates in the data and the model. Figure 9 shows the resulting weights ω_j^{HI}. Table 11 shows that the model performs well in matching the data by age groups. The calibration requires that those age 60 to 64 pay ESI premiums that are about 6 times those paid by 21 to 25 year olds.[36]

Under 2024 law, the Required Contribution Percentage ranged from 0 percent of income for those below 133 percent of the federal poverty line (FPL), to 8.5 percent of income for those who make over 400 percent of the FPL. Under current law, for 2026 and beyond, households earning more than 400 percent of the FPL are ineligible for premium tax credits.[37] We set required contribution percentages in the initial steady state according to 2024 law. We calculate the ACA premium subsidy $\pi_{ACA,t}^{PremSub}(y_t^T) = \max\{\varsigma p_{p,t} - RCP(y_t^T)y_t^T, 0\}$.

because they fear it could prevent them from becoming permanent legal residents. In the model, relatively high wealth may also proxy for an unwillingness to endure the complexity of the enrollment process.

[36] Age-dependent insurance premiums can be rationalized with firms offering a variety of health plans and households of different age groups choosing plans with different benefits and premiums. In 2021, 62 percent of workers whose employer offered health insurance had two or more plans to choose from. See Kaiser Family Foundation (2021).

[37] For more information, see https://tinyurl.com/2fewkerd .

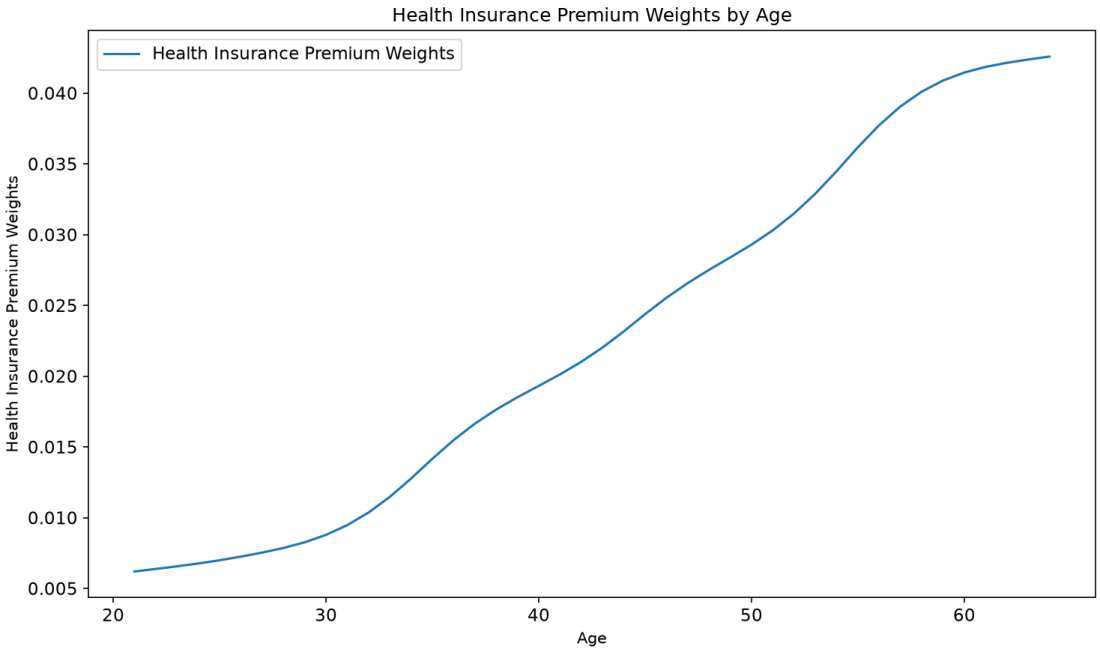


Figure 9: Weights used in calculating health insurance premiums by age

Notes: Weights ω_j^{HI} from Equation 27, which sum to one over ages 21 to 64. They are calibrated to match the uninsured rate by age group.

ς is the average marketplace benchmark premium in 2024 of $540 per month divided by the average monthly single premium per enrolled employee in 2024 of $587 or 0.92.[38]

We calibrate the model to an ACA marketplace enrollment rate of 3.5 percent for 26 to 64 year olds by setting the maximum labor income (aca_{cutoff}) to be eligible for the ACA market at $27,726.84. Enrollment is limited to households that do not qualify for Medicaid and have incomes below the cutoff. As Table 11 shows, we are able to match the aggregate for the 26-64 year old population pretty closely, but we are less successful at matching enrollment by age group, which we do not target. The largest difference is for the group of 21-25 year olds, whose enrollment the model overstates by about 10 percentage points. In the data, that group is likely enrolled in their parents' health plan, or some other group plan (such as through their college), which we do not model. Among 26 to 64 year olds, the largest difference is for the group of 55-64 year olds, whose enrollment the model

[38] See https://tinyurl.com/mryzvk3w.

overstates by about 5 percentage points.

2.6.8 Health Investment

Table 12 compares the model with data on the fraction of the population that forgoes or delays medical treatment.[39] In the model 6.3 percent of the population forgoes medical treatment compared to 12.3 percent in the MEPS data.[40] Our model also captures that uninsured households are much more likely to forgo medical treatment than are insured households, although the model overshoots. In the model 56.3 percent of uninsured forgo medical treatment compared to 29.3 percent in the data.[41] Those results are particularly striking given that we did not attempt to calibrate to data on forgone medical spending. It is the result of our overall calibration strategy and suggests that our model captures households' incentives to insure and seek medical treatment that are broadly consistent with the data.

Table 12: Forgone and Delayed Medical Care Due to Cost

	Model	MEPS Data
All	6.3%	12.3%
Uninsured	56.3%	29.3%

Notes: Data are for 21- to 64-year-old individuals.
Sources: 2019 MEPS Data from the Medical Expenditure Panel Survey.

[39] While there might be a difference between whether somebody delays or forgoes medical treatment, our model cannot capture that nuance as it runs at an annual frequency.

[40] Radley et al. (2021) document large geographic, racial, and ethnic differences in forgone care due to cost. The proportion of white people who cited cost as a barrier to receive care ranged from 6 percent in the District of Columbia and Hawaii to 14 percent in Georgia, Oklahoma, Alabama, and Mississippi. For Black and Latinx people, state rates vary between 9 percent in California (Black) to a high of 30 percent in Tennessee (Latinx).

[41] Collins et al. (2020) document that under-insured and uninsured are 2 to 3.5 times more likely to forgo needed medical care and medications and that 56 percent of the uninsured avoided needed medical care.

Table 13: Life Expectancy, Model versus Data

	Life Expectancy at Age	
	21	65
Model Benchmark Economy	60.6	21.3
Census Bureau	59.9	20.1
Centers for Disease Control and Prevention	58.3	19.5
Congressional Budget Office		19.7
Social Security Administration	57.3	18.9

Sources: Census Bureau data for 2020 from https://www.census.gov/content/dam/Census/library/publications/2020/demo/p25-1145-supplemental-tables.pdf ; CDC data for 2023 from https://www.cdc.gov/nchs/data/nvsr/nvsr74/nvsr74-06.pdf, Table 1; Congressional Budget Office projections for 2025 from https://www.cbo.gov/publication/61164, Table A-1; SSA data for 2022 as of 2025 from https://www.ssa.gov/oact/STATS/table4c6.html

2.6.9 Life Expectancy

Our model projects life expectancies that are generally consistent with US government projections as shown in Table 13. Our model projects that 21-year-olds can expect to live 60.6 years, on average, compared to 59.9 years based on projects by the Census Bureau, 58.3 years by the CDC, and 57.3 years by the SSA. Our projections of the life expectancy for 65-year-olds is 21.3 years, compared to a range of 18.9 to 20.1 years by the Census Bureau, the CDC, the CBO, and the SSA.

2.6.10 Aggregate Health Spending

Table 14 shows total health spending by payer as a share of GDP and compares those to 2024 data from the National Health Expenditure Account (NHEA).[42] Model per-person spending is MEPS spending scaled to NHEA spending on the MEPS scope (Section 2.6.1), so it excludes spending outside that scope, such as nursing home care and care of the institutionalized population. We therefore scale the model's private insurance, Medicare

[42]We compare our data to the Personal Health Care and Total Administration and Total Net Cost of Health Insurance Expenditures categories of the 2024 National Health Expenditures. Those two categories make up more than 90 percent of the 2024 National Health Expenditures. The remainder includes Public Health Activities and Investments in Research, Structures and Equipment, which we do not explicitly model.

and Medicaid outlays by fixed factors that approximately equal the ratio of 2024 NHEA spending to model spending after the MEPS adjustment. The factor is largest for Medicaid, because Medicaid is the largest payer of long-term care. Out-of-pocket spending and private insurance premiums are not scaled. Total health spending is 13.3 percent of GDP in the model and 13.4 percent in the NHEA data, and spending by each payer is within 0.1 percentage points of the data. The model generates average private insurance premiums of $8,659, about 2 percent more than the $8,486 that the Kaiser Family Foundation reports for 2024.

Table 14: Aggregate Health Spending as a Share of GDP

	Model	NHEA Data
Payments to providers		
Private insurance	5.0	5.0
Medicare	3.6	3.6
Medicaid (federal share)	1.9	1.9
Out-of-pocket	1.8	1.9
Administration	1.0	1.0
Total health expenses	13.3	13.4
Average private health insurance premium	$8,659	$8,486

Notes: Private health insurance premiums are in US$. NHEA data is for the "Personal Health Care" and the "Total Administration and Total Non-Medical Insurance Expenditures" categories. It includes data for Private Health Insurance, Medicare, and the federal portion of Medicaid. It excludes spending on Public Health Activity, Investments in Research, and Structures and Equipment.
Sources: NHEA spending data for 2024 from the National Health Expenditure Account: https://www.cms.gov/data-research/statistics-trends-and-reports/national-health-expenditure-data/historical , https://www.cms.gov/files/zip/national-health-expenditures-type-service-source-funds-cy-1960-2024.zip
Data for the 2024 average annual single premium per enrolled employee for employer-based health insurance from the Kaiser Family Foundation:
https://www.kff.org/private-insurance/state-indicator/single-coverage/?currentTimeframe=1&sortModel=%7B%22colId%22:%22Location%22,%22sort%22:%22asc%22%7D.
Penn Wharton Budget Model calculations.

2.7 The Social Security and Hospital Insurance System

The Social Security Old-Age, Survivors, and Disability Insurance (OASDI) and Medicare Hospital Insurance (HI) system closely mirrors current U.S. law. The payroll tax func-

Table 15: Values of Government Policy Parameters in the Benchmark Economy

Parameters		Value	Comment
Income taxes			
Taxable labor income ratio (change to Payroll Tax Base Share)	η_1^y	0.8641	T_P / GDP = 5.1%
Payroll Base Deduction	η_0^y	\$6,000	To approximate the distribution of payroll tax revenues across income groups.
Social Security system			
Medicare pay roll tax rate: HI	τ_{HI}	0.029	
: HI surtax	τ_{HI2}	0.009	
HI surtax threshold	ϑ_{HI}	1.6245	0.4 x \$200,000 + 0.6 x \$250,000

Source: Penn Wharton Budget Model.

tion includes OASDI payroll taxes that are levied on taxable earnings up to the statutory maximum, HI payroll taxes levied on all taxable income and a HI surtax levied on income above \$200,000 for single filers and \$250,000 for joint filers. The OASI primary insurance amount is calculated based on a household's average historical earnings. We report the parameters of the OASDI and HI system in Table 15.

We define the OASDI/HI payroll tax function to be

$$\tau_{P,t}(y_t^T) = \tau_{O,t} \min(\eta_1^y(y_t^T - \eta_0^y), \vartheta_{\max}) + \tau_{HI,t}\, \eta_1^y(y_t^T - \eta_0^y) + \tau_{HI2} \max(\eta_1^y(y_t^T - \eta_0^y) - \vartheta_{HI}, 0),$$

where $\tau_{O,t}$ is the flat OASDI tax rate, $\tau_{HI,t}$ is a Hospital Insurance (Part A of Medicare) tax rate, and τ_{HI2} is an HI surtax rate for households with high labor income (covered earnings greater than \$200,000 for single taxpayers and \$250,000 for married couples filing jointly). The first three tax rates include the portion paid by employers. When labor income is below the threshold of maximum taxable earnings, the statutory OASDI tax rate is 12.4 percent, including 6.2 percent paid by employers; thus, $\tau_{O,t} = 0.124$. The effective HI tax and HI surtax rates are set at $\tau_{HI,t} = 0.029$, and $\tau_{HI2} = 0.009$, respectively. The maximum taxable earnings per worker for the OASDI payroll tax were about \$170,000 in 2024. The HI

surtax threshold ϑ_{HI} is set at about \$230,000 per household, the average of the single and married-filing-jointly thresholds weighted by the share of married households (about 60 percent). Because the model is based on household units, that single-worker figure must be translated to the household level. We assume that 60 percent of households are married households, of which two-thirds are two-earner households—meaning that 40 percent of all households are two-earner households.

2.8 Production Technology and Wages

In our baseline model specification, we assume a single intermediate goods sector ($n = 1, \zeta_1 = 1$). We currently keep α_1^f fixed across time and set it to 0.45 based on Microsim calculations. In the section below, the subscript b denotes the business-type (corporate or pass-through), j denotes the business sector (the type of output, set to 1 in the default case of a single intermediate-goods sector), and t is the year.

2.8.1 Business income

U.S. business taxation has two main treatments: corporate and pass-through. Corporations are business entities which are subject to taxation at the entity level while pass-throughs are business entities (such as partnerships, some limited-liability companies, subchapter S corporations, and sole proprietorships) for which tax liability is shifted onto the pass-through entity's owners. All business tax parameters are generated from from historical data and projections in the PWBM tax simulator. The choice between investing in pass-through versus corporate business is not modeled in the OLG model, which takes these decisions as exogenous, and all households hold the same proportion of pass-through and corporate assets.

All of the main parameters in the dynamic OLG model for business taxation come from either historical data or projections contained in the PWBM tax simulator. The parameter $\zeta_{b,1,t}^{ded}$ is the share of firm GDP which is the base for other tax deductions. It is calculated

as the residual that equalizes OLG-basis taxable income and conventional-basis taxable income for each business type (corporate or pass-through) b. For the 2024 initial steady state it is set to 0.034 for the corporate sector and 0.221 for the pass-through sector. The parameter $\zeta^{cred}_{b,1,t}$ denotes the share of production that is subject to the production tax credit. For 2024 initial steady state the share is set to 0.0075 for the corporate sector and 0 for pass-throughs. $\zeta^{itc}_{b,1,t}$, the share of investment credits is set to zero for all firms. The parameter $\zeta^{other}_{b,1,t}$ is other business expenses is set to 0.091 and 0.083 for corporate and pass-through firms, respectively, and the economic depreciation rate of capital $\delta_{1,t} = 0.056$; these two parameters are kept constant across time in the baseline, while $\zeta^{ded}_{b,1,t}$ and $\zeta^{cred}_{b,1,t}$ vary by year with the PWBM tax simulator projections. The share of borrowing or interest expenses that are eligible to be deducted is $\phi^{int}_{b,j,t}$, and it is the same for both pass-throughs and corporations. We set it to 0.898 in the 2024 initial steady state; it also varies by year with the PWBM tax simulator projections.

We currently exogenously set interest rate that the firm pays on business debt is $\rho_{corp,1,t} = 7.0$ percent. We assume that all deductions, $\phi_{b,j,t,i}$ occur over a $T_d = 40$ year schedule that comes from the PWBM tax simulator. The tax deduction schedule is computed separately for each sector and business-type and is based on approximating the capital mixes in the economy and the various depreciation schedules in the tax code that are applied to different types of capital.

In the current model, we take $\nu_1 = 3.5$ following Glover, Gomes, and Yaron (2015) and the leverage ratio $B_{corp}/K_{corp} = 0.32$ from Barro and Furman (2018) and Graham, Leary, and Roberts (2015). Using these values, we derive (and assuming a time invariant statutory tax rate, $\tau^{statutory} = 0.21$) $\nu_2 = 1.62$ from (40),

$$\nu_2 = \left(\frac{\tau^{statutory} \phi^{int}_{corp} \rho_{corp,1,t}}{1 - \tau^{statutory} \phi^{int}_{corp}} \right)^{-\frac{1}{\nu_1 - 1}} \frac{B_{corp}}{K_{corp}} \tag{82}$$

These time-invariant values of ν_1 and ν_2 are used for all policy runs under the assumption

that the leverage cost function depends only on the leverage ratio.

Given α_1^f and the targeted capital–output ratio of 3.0, we normalize $A_{1,t} = 0.845$. In the initial steady state this implies wages $w = 1$. η, the adjustment cost of capital parameter is assumed to be 1.

2.9 Transfers

2.9.1 OASI Benefits

One of the key features of the dynamic OLG model is its model of OASI benefits, $tr_{OASI,t}(j, b, p_{t-j}^t)$. The OASI benefit is a time-varying function of age (j); the average number of adults in the household ($\Omega_{a,T_0}(j)$), which itself is a function of age; and the average real wage in the economy in the year the household turns 60 years of age ($w_{t(j=60)}$), itself an element of the set of historical prices ($p_{T_0}^{T_f}$).

The schedule of OASI benefits $tr_{OASI,t}(j, b, p_{t-j}^t)$ is a piecewise linear function with Z vertices (including 0), which we call primary insurance amount (PIA) bend points. Specifically, for a household with $b \geq 0$ earnings history with PIA bend points $PIA_{z,j,t}$ and PIA income replacement rates $PIA_{z,j,t}^r$ for age j and time t, the OASI benefit is defined as:

$$tr_{OASI,t}(j, b, p_{t-j}^t) = \sum_{z=1}^{Z} max[0, min(b - PIA_{z,j,t,p_{t-j}^t}, PIA_{z+1,j,t,p_{t-j}^t} - PIA_{z,j,t,p_{t-j}^t})]PIA_{z,j,t}^r \Omega_{a,t}(j)$$

where PIA_{Z+1,j,t,p_{t-j}^t} is not an actual vertex on the piecewise linear line, but rather set to be higher than the largest value on the support of b. In the baseline and any policy function, We multiply these rates by the number of adults ($\Omega_{a,t}(j)$) to approximate the total household OASI benefit. Under current law, there are four PIA bend points (including 0) with corresponding PIA income replacement rates of 0.9, 0.32, 0.15, and 0.0.

The primary insurance amount (PIA) parameters—both bend points (PIA_{z,j,t,p_{t-j}^t}) and PIA income replacement rates ($PIA_{z,j,t}^r$)—are drawn from the PWBM OASDI calculator,

which provides this information in each year and for each cohort. The OASDI calculator provides these values based on current and forecast economic projections; the forecast projections underlying these values may differ from the projections in the dynamic OLG model. In particular, the average wage index (AWI)—both real and nominal—may differ from the projections used to construct the PIA brackets, especially as economic conditions change in response to changes in other economic assumptions or changes in policies.

Therefore, we construct the PIA brackets used in the dynamic OLG model for each bracket z, age j, and year t

$$PIA_{z,j,t,p^t_{t-j}} = \frac{PIA^{OASDI_calc}_{z,j,t}}{AWI^{OASDI_calc}_{t(j=60)}} w_{t(j=60)}$$

where $PIA^{OASDI_calc}_{z,j,t}$ is the PIA bend point provided by the OASDI calculator, $AWI^{OASDI_calc}_{t(j=60)}$ is the nominal AWI series used by the OASDI calculator, and $w_{t(j=60)}$ is the real average wage (wage income divided by hours worked) used by the dynamic OLG model. The real average wage, $w_{t(j=60)}$, is endogenous, so as policy changes the average wages for households at age 60, the OASI benefits change as well.

2.9.2 Supplemental Nutrition Assistance Program (SNAP)

This transfer program has been design to help low income households achieve a nutritionally adequate diet.

2.9.2.1 Eligibility Requirements

Eligibility is determined at the household level. Legislated SNAP requirements are based on household size. To accommodate the non-integer family sizes we have in the model, we approximate the legislated eligibility rules linear.

1. Gross income limit (GIL): $GIL_t(j) = G\bar{I}L_t + G\hat{I}L_t(\Omega_{a,t}(j) + \Omega_{c,t}(j))$. For 2024, $G\bar{I}L_t =$

$\$11,286$ and $\hat{GIL}_t = \$6143$.

2. Net income limit (NIL): $NIL_t(j) = \bar{NIL}_t + \hat{NIL}_t(\Omega_{a,t}(j) + \Omega_{c,t}(j))$. For 2024, $\bar{NIL}_t = \$8,689$ and $\hat{NIL}_t = \$4719$.

3. Assets: For 2024, households must have $2,861 or less in assets, a. If the head of the household age is at least 60 years old, the limit goes up to $4,422.

For households over 59 years old, the only eligibility requirement is the asset requirement; the income limits do not apply. More generally, eligibility and benefit levels depend on net income and gross income as defined by the SNAP rules. Gross income is the sum of paid labor income, dividend income, OASI benefits, SSI benefits and SSDI benefits (which are set to 0 in the baseline economy). Section A income, y^{secA}, is 80 percent of gross income less a standard deduction. In 2024, the standard deduction is $2,210. Net income, y_t^{NI} is then Section A income less a shelter deduction, $SD_{snap,t}$, where:

$$SD_{snap,t} = \min\{SC_t - 0.5y_t^{secA}, \mathbb{1}_{a<60}SC_t^{MAX}\} \tag{83}$$

For 2024, $SC_t = \$12,397$ and $SC_t^{MAX} = \$7,791$.

The maximum benefit that a household can receive depends on its size. To accommodate for average household size, we perform linear interpolation: Benefit limit, $BL_t(j) = \bar{BL}_t + \hat{BL}_t(\Omega_{a,t}(j) + \Omega_{c,t}(j))$. For 2024, $\bar{BL}_t = \$774$ and $\hat{BL}_t = \$2,357$.

Eligible households receive a SNAP benefit $\tilde{SN}_t(s,l) = \max\{0, BL_t - 0.3y_t^{NI}\}$. We top up this benefit if the total resources a household has falls below $\$11,600$. Total resources are defined the net of assets, a, paid income, y_t^P, SNAP benefits $\tilde{SN}_t(s,l)$ and any tax credits for insurance premia less insurance premia paid and tax liabilities. The total transfer the household receives is $SN_t(s,l) = \tilde{SN}_t(s,l)$+ resource shortfall.

2.9.3 Supplemental Security Income (SSI)

This federal assistance program provides cash payments to aged, blind, or disable individuals with limited income and resources. To be eligible in the model, the household must (1) be aged 65 or over; (2) have assets, a, below a limit ($2,080.80 in 2024).

The household SSI benefit, $SSI_t(s, l)$ is difference between the maximum SSI benefit ($9,912.93 in 2024) and a households "countable income." If paid labor income y_t^P is less than the SSI general deduction ($249.70 in 2024), the household's countable income is the maximum of the sum of y_t^P, dividend income, OASI benefits and SSDI benefits less the SSI general deduction or $0. If y_t^P is greater than the SSI general deduction, countable income is the sum of "countable labor income" and dividend income, OASI benefits and SSDI benefits, where countable labor income takes y_t^P less both the SSI general deduction and the SSI earned income deduction ($811.51 in 2024) and multiplies the results by 50%. If countable labor income is less than 0 as a result of this calculation, it is set at $0.

2.10 Government Budget

Most of the previously-described parameters were calibrated so that so that large categories in the government budget were broadly consistent between the model and the observed U.S. federal budget in the model's starting year. Table 16 shows the government's budget in the stationary-population benchmark economy and the data.

In the initial steady state, we set discretionary spending to its value in the data and introduce a category, "Adjustments," so that debt held by the public at the end of the year matches the data. Along the transition path, we update this category only to keep the total primary deficit consistent with the data. Because debt is matched in the initial steady state, the model requires no further adjustment.

We set the distribution of federal debt and the effective coupon rate for each year's vintage of debt to match its empirical distribution of marketable securities (excluding TIPS

Table 16: The Government's Budget in the Benchmark Economy

Percentage of gross domestic product	Model	Data
Revenues		
Individual income taxes	7.9	8.4
Payroll taxes	5.4	5.9
Corporate income taxes	2.3	1.8
Other revenues	0.8	0.9
Total revenues	16.4	17.1
Outlays		
Mandatory		
Social Security	4.8	5.0
Medicare	3.1	3.2
Medicaid	2.1	2.1
Other mandatory	2.5	4.0
Total mandatory	12.5	14.3
Discretionary	6.3	6.3
Net interest	2.9	3.1
Total outlays	21.7	23.7
Adjustments	1.3	
Total deficit (−) or surplus	**−6.6**	**−6.6**
Memorandum:		
Primary deficit (−) or surplus	−3.6	−3.6
Debt held by the public, end of year	97.8	97.8

Notes: In percent of gross domestic product (GDP). Data for 2024.
Adjustments are treated as discretionary outlays and do not affect households directly. They include a lump-sum outlay that sets deficits to their data value. In the model, the total deficit equals total revenues minus total outlays minus adjustments.
In the data, the total deficit equals total revenues minus total outlays.
Components may not sum to totals because of rounding.
Sources: Congressional Budget Office (2025) and Penn Wharton Budget Model.

and Floating Rate Notes) in the Monthly Statement of Public Debt at the end of December of the steady-state year. The total amount of federal debt is set so that it matches Debt Held by the Public at the end of the year.

2.10.1 Personal Income Taxes

The dynamic OLG model's tax schedule is derived from the PWBM tax simulator. The PWBM tax simulator generates a huge number of tax filings (records) that are then distilled into (1) an effective deduction schedule broken down into 19 brackets and deduction shares; (2) an effective marginal ordinary tax schedule with 19 brackets and rates; (3) an effective marginal preferred income tax schedule with 6 brackets and rates; and (4) a refundable credit for each of five age groups. All brackets, rates, and burdens are fixed in real values (or fixed percentages) after 2055.

We start with a schedule of deductions. The first step is to define the basis of compensation in the OLG model to which the deduction schedule is applied. In the dynamic OLG model, we apply deductions to a very broad definition of compensation: all taxable compensation that could be taxed at the non-preferred rate. This includes labor income, business income taxed at the ordinary rate, dividend income from U.S. federal debt, and all OASI income. Note that this excludes non-OASI transfers such as SNAP or ACA subsidies. The deduction schedule is meant to approximate all major deductions from taxable total compensation excluding employer-sponsored healthcare premia deductions, which are handled separately in the model.

To find a comparable measure of income in the PWBM household tax simulator to use as our basis for approximating a deduction schedule to be used in the dynamic OLG model, we take adjusted gross income and add back elective deferrals (doubled) and payroll deductions (doubled).[43] The deduction share is computed as the sum of elective deferrals (doubled), above-the-line deductions, and the itemized or standard deduction. We com-

[43]Elective deferrals and payroll deductions are reported as the household expense only; we double these values to capture the employer contributions to both of these categories.

pute deductions as a share of this income in every year across five different age groups (21–29, 30–39, 40–49, 50–64, and 65–100) for 19 income brackets whose thresholds are determined by every decile, plus the 2.5th, 5th, 7.5th, 95th, 96th, 97th, 98th, 99th, and 99.9th percentiles. The deduction share for each of these bins is equal to a weighted average of the deduction share among all filers in these bins. This schedule is imported and applied in the OLG model to each household based on the compensation measure defined above.

In the dynamic OLG model, after applying this deduction share, we are left with a measure of income that closely approximates income taxed at the ordinary rate, or "ordinary income." The next step is to import a set of marginal tax rates that are approximated from data in the PWBM household tax simulator, also based on ordinary taxable income.

In order to construct the same 19-bracket, 5-age-group, yearly schedule described above for ordinary marginal tax rates, we start by computing effective marginal tax rates in the PWBM household tax simulator. The PWBM tax simulator estimates an effective marginal rate for every filer by adding ordinary income (either labor for working-age people or OASI benefits for retirees) and recomputing the filer's tax liability. The change in tax liability over the change in income is the marginal effective rate. Note that this effective tax rate may include the effects of certain tax credits, most notably the Earned Income Tax Credit, whose value changes significantly as ordinary income changes.

As before, we take a weighted average of the marginal effective tax rate for all of the filers in each of the bins defined by year, age group, and 19 income groups computed using the same percentiles but applied to ordinary taxable. We pass the schedule to the dynamic OLG model. The dynamic OLG model takes this schedule of marginal effective tax rate to the household ordinary income, which results in the household ordinary tax liability.

We also need a separate tax schedule for preferred income in the OLG model. In the dynamic OLG model, a share of total compensation comes from business income, and a large share of corporate business income is taxed at the preferred rate. We use the PWBM household tax simulator to generate a marginal effective tax rate on this preferred income.

The age bins for the preferred schedule remain the same as before, however, instead of 19 brackets, we have 6 brackets whose thresholds are the 0th, 50th, 90th, 95th, 99th, and 99.9th percentiles of income based on household preferred distributions. As before, the PWBM household tax simulator computes the marginal effective rate for each filer for preferred income. We construct a weighted average of this marginal effective preferred tax rate for each of the bins to create the preferred tax schedule used by the OLG model. The preferred tax schedule in the dynamic OLG model is applied to only the preferred share of household income.

Finally, the income tax function has an intercept, the refundable credit $rc_t(j)$, which the household receives regardless of its income. Households with little or no ordinary income can still receive refundable credits, most notably the Earned Income Tax Credit, so their income tax liability is negative. For each year and each of the five age groups, we set $rc_t(j)$ to the weighted average refundable credit among filers in the PWBM household tax simulator who have zero ordinary income. The OLG model deflates these nominal values by the CPI-U.

2.10.2 Payroll Taxes

Payroll taxes brackets and rates are set to their statutory values in each period.

2.10.3 Estate Taxes

The estate tax has two brackets and rates; a rate of 0.0 percent for the first bracket and a rate of 40.0 percent for the second bracket, both set to their statutory values. The threshold for the bracket is currently set at $3.0 million. This generates about $23 billion in estate tax receipts in the dynamic OLG model in 2024, consistent with 2024 statistics on the revenues from estate and gift taxes.

2.10.4 Consumption / VAT Taxes

In the default model, the consumption or VAT tax is set to 0.0 percent in all cases. The number of brackets and rates can be adjusted for policy analysis.

2.10.5 Business Taxes

Many of the parameters for the corporate / business tax were defined in section 2.8. The corporate statutory tax rate, $\tau_{corp,j,t}^{statutory}$, is set to its current-law value of 21.0 percent in the baseline in all years.

2.10.6 State Income Taxes

The value for the state taxes are set to fully fund state obligations for SNAP and Medicaid. The parameter, $\tau_{state,t}$, is the state tax applied only to a share of taxable labor income (total taxable labor income times a percent that is allowed to be deducted). This value is set endogenously in the model.

2.10.7 Interest Rates on U.S. Federal Debt

In this initial steady state, the distribution of coupon rates on federal debt is sorted by vintage. For example, debt maturing in two years has a coupon rate that is the weighted average of all outstanding marketable issues (excluding TIPS and Floating Rate Notes) that mature in two years. We compute this average effective coupon rate in each maturity year for all federal debt maturing in the next 30-year period from the Monthly Public Statement of Debt from the U.S. Treasury for December in the steady state year. The yield curve for future debt is estimated as part of the PWBM Microsim forecast process.

2.11 Foreign holding of U.S. Federal Debt

We set $\phi_t^D = 0.3$. For each dollar of new net issues, which is defined as the total new debt issues minus the retired debt (debt with a maturity of one year at the beginning of the period), $\phi_t^D = 0.3$ get purchased by foreign investors. PWBM has published its estimates of foreign take-up of U.S. federal debt at (https://budgetmodel.wharton.upenn.edu/issues/2020/9/21/capital-flows-update). Historically, this value has been closer to 40 percent, however, in recent years, a decline in foreign ownership of U.S. debt has reduced the long-run average of foreign take-up of debt to about 30 percent.

2.12 The maturity structure

In the first year of the simulation (T_0), we need the vector for the effective coupon rates ey_{T_0} and the vector of the amount of outstanding debt at the end of the previous period d_{T_0-1}. To construct the beginning-of-year distribution in year time T_0, we use information from the December issue of the Monthly Statement of the Public Debt of the United States in year $T_0 - 1$. To construct the distribution, we limit ourselves to marketable securities. From these the marketable securities, we exclude Treasury Inflation Protected Securities (TIPS) and Floating Rate Notes. We define this set of securities $TREAS$, which are the set of treasury bonds, bills, and notes. For a single issue in this set of securities $\Lambda \in TREAS$ we define $mat(\Lambda)$ as the security's maturity in years, $out(\Lambda)$ as the security's outstanding value, and $int(\Lambda)$ as the security's coupon rate (the coupon for bonds and notes, which are typically sold close to par, and yield for bills, which are typically sold below par). From this population of Treasury bills, bonds, and notes, we construct each element of d_{T_0-1}, which corresponds to each maturity i for the next 30 years:

$$d^i_{T_0-1} = \frac{\sum_{\Lambda}^{TREAS} out(\Lambda) I[mat(\Lambda) = i)]}{\sum_{\Lambda}^{TREAS} out(\Lambda)} \tag{84}$$

where $I(.)$ is an indicator function.

We construct the average coupon rate using the weighted average of the interest rates from each maturiy of debt:

$$ey^{i}_{T_0-1} = \sum_{\Lambda}^{TREAS} int(\Lambda) \frac{out(\Lambda)}{\sum_{\Lambda}^{TREAS} out(\Lambda) I[mat(\Lambda) = i)]} I[mat(\Lambda) = i)] \tag{85}$$

3 Baseline Dynamic OLG Simulations

All of PWBM's dynamic analysis starts with a baseline simulation. A baseline simulation is a set of government policies ψ_t, health insurance premium growth rates $\nu_{i,t}$ and age-dependent Microsim population levels $\hat{x}_t^{\text{microsim}}(j)$, survival rates, $\delta_{j,t}^{microsim}$, emigration probabilities em_t, and immigration levels im_t for all $t \in [T_0, ...T_c, ..., T_f]$. In most simulations, government policies ψ_t and immigration levels are based on current laws, although in some analyses the baseline policy may deviate from current law depending on the needs of policy analysis.

We solve the transition path to find a competitive equilibrium, defined in Section 1.7. The initial conditions for the transition path, including the initial household and firm distributions, and initial levels of government debt and foreign debt ownership, are inherited from the Competitive Equilibrium in the Initial Steady State described in Sections 1.8 and 2. Below we describe the time-varying inputs for the model.

3.1 Time-Varying Parameters

The dynamic OLG model uses a number of exogenous price indices, the values of which change in levels and growth rates over time. These include an index of consumer price index for all urban consumers (CPIU), the Microsim average wage index (AWI), the GDP price index (PGDP), and excess cost growth for medical services paid for privately, Medicare, and Medicaid.

We forecast expected future yield curves using Microsim: $yc_t : \mathcal{T}_{\Updownarrow} \rightarrow \mathbb{R}$, where $\mathcal{T}_{\Updownarrow} = \{1, 2, ..., T_m\}$. In the typical baseline specification, the yield curve is time varying and each point on the yield curve asymptotes over the course of the simulation.

In the baseline specification, total factor productivity (TFP) grows at a constant rate over time. Nonetheless, there may be idiosyncratic changes or even level shifts to TFP based on changes to public infrastructure investment or, in some specifications, changes

in the composition of the education of working-age immigrants.

3.2 Time-Varying Population Levels

Our model takes as input the time-varying population levels for each age group, which are derived from the PWBM Microsim. These population levels are denoted as $\hat{x}_t^{\text{microsim}}(j)$ for age j at time t. As in the model, the population is measured in households, and the age of a household is the age of its head. In the Microsim data, the number of households of each age changes over time for the following reasons:

- **Aging.** Households that remain in the population move from age j in year t to age $j+1$ in year $t+1$, so differences in the size of cohorts move through the age distribution over time.

- **Entry at age J_B.** Households enter the population when their head reaches age $J_B = 21$ ("birth" in the model). Births in the Microsim therefore affect the model's population only once the children reach age J_B and head their own household.

- **Immigration.** Households enter at any age when their head immigrates, $im_t(j)$.

- **Death.** A household exits when its unmarried head dies, $de_t(j)$, and every household exits when its head reaches age $J_D = 100$.

- **Emigration.** A household exits when its unmarried head emigrates, $em_t(j)$.

- **Household formation and dissolution.** Households also form and dissolve while their members remain in the population, for example when marriage combines two households into one or divorce splits one household into two.

- **Change of head.** Deaths and emigrations of married heads are not counted as exits. When a married head dies, the surviving spouse becomes the head, and the household is counted at the spouse's age.

- **Moves between groups.** When the population is divided into several demographic groups, households also move from one group to another (Appendix B). With the single group of the baseline, these moves do not occur.

The model represents entry at age J_B, immigration, death, and emigration explicitly. The population of age J_B is set to $\hat{x}_t^{\text{microsim}}(J_B)$, the survival rates are calibrated to the Microsim survival rates $\delta_{j,t}^{\text{microsim}}$ (Section 2.6.4), and the emigration probabilities and immigration levels are taken from Microsim (Section 1.2.2). Household formation and dissolution and changes of head are not represented; the scaling vector (Section 1.2.3) absorbs their effect on the population, so that the model's population at each age matches $\hat{x}_t^{\text{microsim}}(j)$.

3.3 Time-Varying Government Policies

3.3.1 Government Policies Affecting the Household

The individual income tax, $\tau_{I,t}\left(y_t^T, \tilde{r}_t a, tr_{OASI,t}(j, b, p_{t-j}^t), \iota\, oop_t, rc_t(j)\right)$, is the largest revenue component for the government. The income tax schedule contains the deduction schedule for ordinary income, the ordinary tax schedule, the preferred tax schedule, the cap $\overline{oop}_t$ on the deduction of out-of-pocket medical spending, and the refundable income tax credit $rc_t(j)$. The payroll tax $\tau_{P,t}$ is a separate schedule that applies to taxable labor income. Its time-varying components are the payroll tax schedule, the share of labor income subject to the payroll tax, and the share of pass-through income added to the payroll tax base, which is zero in the baseline.

OASI benefits can change as the schedule changes over time; so $tr_{OASI,t}(j, b, p_{t-j}^t)$, the PIA brackets $PIA_{z,j,t}$ and PIA income replacement rates $PIA_{z,j,t}^r$ are time varying.

The estate tax function $\tau_{E,t}$ piecewise linear function. In the baseline, the estate tax rate is set to zero below some threshold, and a fixed rate for all values above the estate tax threshold. Although these values are fixed in the baseline, both the threshold value,

the number of thresholds, the rate, and the number of rates can vary over time. The value of the estate at death is reduced by a schedule $\Xi(a')$ containing a fixed value (representing fixed costs of associated with debt such as probate and burial) as well as a share of the estate (representing charitable contributions, end-of-life care, and other end-of-life expenses). The estate tax schedule is applied to the residual value of the estate. The fixed value and the share of the estate excluded from taxation do not vary with time and are fixed parameters.

SNAP benefits, $SN_t(s,l)$, and Supplemental Security Income (SSI), $SSI_t(s,l)$, are determined by formulas that takes a large number of time-varying parameters including deductions, thresholds, and benefit rates, as described in Sections 2.9.2–2.9.3. All of these parameters vary with time.

3.3.2 Exogenous Government Revenues and Outlays

The government budget constraint has a number of exogenous components to it that can vary over the transition path. On the revenue side of the budget constraint, the budget categories that constitute $T_{exog,t}$ and change over time are the customs duties, miscellaneous receipts, excise taxes, gift taxes, and lump sum taxes. The lump sum tax is typically set to zero in the baseline, but is a value that can be used to cover any number of other categories in a policy experiment.

The spending side has a number of time-varying budget parameters including discretionary spending, disability benefits, federal retirement spending, veterans programs, infrastructure spending, CHIP and other programs that constitute aggregate exogenous outlays, $C_{G,t}$. In the baseline, infrastructure spending is set to zero; in policy analysis, infrastructure spending reflects deviations from baseline total public infrastructure spending and can be set to a negative value reflecting a decrease in public infrastructure investment.

3.3.3 Government Policies Affecting the Production Sector

Most of the firm tax variables change over the transition path as well. The statutory business tax, $\tau_{b,j,t}^{statutory}$, can vary over time, although it is typically set to zero for all pass-through businesses in all years. The production credit parameter, $\zeta_{b,j,t}^{cred}$ can also vary across time. As is the case for the statutory rate, the value of production credits for pass-through businesses are typically set to zero.

General business income deductions, $\zeta_{b,j,t}^{ded}$, are another variable that is typically time varying over the transition, as is the fraction of interest that is tax deductible, $\phi_{b,j,t}^{int}$. The expensing schedule, $\phi_{b,j,t,n}$ varies considerably over time for both the corporation and pass-through.

4 Static and Dynamic Policy Simulations

To conduct policy analysis, PWBM constructs a counterfactual set of inputs for the simulation. In most cases, these take the form of an alternative set of government policies, ψ_t' or demographic assumptions, $\hat{x}_t'^{\text{microsim}}(j)$. Using these inputs, the dynamic OLG model has the capacity to provide two different types of simulations: a static policy simulation and a dynamic policy simulation.

4.1 Static policy simulation

The static policy simulation is a simulation in which only select elements of the competitive equilibrium are satisfied in the solution. In particular, in the static policy simulation, we do not require markets to clear, we do not require health insurers earn zero profits and we do not update the set of household policy functions. Specifically, when computing the static policy simulation, we use the original set of household policy functions (Γ_h), the same household distribution (X), and some features of the original business functions ($\{\Gamma^f_{b,j}\}_{\{corp,pass\},\{1,\ldots,n\}}$, and Y_{T_0}) from the baseline.

The static policy simulation is designed to be comparable to the conventional scoring process. In conventional scoring, changes to the tax code are applied to the same filers with the same household characteristics; adjustments are not made for changing economic conditions, changing demographics, or changes in personal behavior. The static policy simulation generates comparable sets of estimates for most changes to household- and business-related policy variables. Businesses continue to rent the same amount of business capital and employ the same amount of labor. However, the firm can choose different levels of debt to minimize their tax liabilities.

This simulation gives us a view of how agents would be affected in the absence of dynamic economic feedback and provides a way to validate the more parsimoniously-specified dynamic OLG model (in which household states are limited to age, savings,

health, earnings history, productivity, insurance, and demographic groups) against the more richly specified PWBM tax simulations and Microsimulations, which have much larger state spaces but lack dynamic feedback.

4.2 Adjusting inputs using static simulation

PWBM has a number of modeling modules that it can use to conventionally score policy proposals. In order to generate that conventional score, PWBM needs to run two simulations: one based on a baseline set of inputs and another on a counterfactual set of policy inputs. For example, conventional score of a proposed policy that increased the top marginal statutory rate to 50 percent would require two household policy simulations: a baseline household tax simulation run based on current law, and then another policy simulation using the same filers but with a top statutory rate of 50 percent. The aggregate difference in personal income tax revenues between the baseline and the policy is called the conventional score.

To run a similar experiment in the dynamic OLG model, we would use a set of baseline government policies ψ_t and a set of counterfactual government policies ψ'_t. In this case, we would use the baseline household tax simulation output to generate schedules of effective marginal tax rates, deductions, and credits (described in section 2.10.1) to get the baseline tax schedule in ψ_t for the dynamic OLG model. Similarly, we would use output from the household tax simulator for the alternate policy to generate the schedule of government policies ψ'_t for use in the counterfactual policy simulation.

The differences for budgetary indicators between the baseline policy simulation and the static policy simulation is called the static estimate. The static estimates generated from the dynamic OLG model may differ from the conventional estimates of the same budgetary indicators for many reasons. Two of the biggest reasons, however, are differences in the models themselves and differences in the distribution of households in each simulation.

As noted earlier, we use the simulated household tax simulation to generate an effec-

tive marginal tax, deduction, and credit schedule by age and by year. Unlike the PWBM household tax simulator, which faithfully simulates the 1040 and its schedules in great detail, the dynamic OLG relies on a reduced-form schedule so that the model remains mathematically and computationally tractable. The simpler tax schedule used does not perfectly replicate the nuances of the full forms used by the household tax simulator, leading to differences in the static and conventional scores.

Another important difference is in the distribution and weights of households. The dynamic OLG model generates an endogenous distribution of household wealth, earnings history, health, and other indicators that may not identically match the distribution used by the PWBM tax model. Although PWBM puts a lot of effort into generating earnings processes that faithfully replicate the main features of the U.S. economy and calibrating the model to generate household behavior that matches the effects observed in modern research, there are still going to be differences in the distribution of household characteristics in the dynamic OLG model and the distribution used by the PWBM, Microsim and Tax model, which may lead to differences between the static and conventional estimates.

The change in government debt is an important driver of macroeconomic conditions in the dynamic OLG model, so there are times when we want to adjust our inputs so that the static estimates in certain budget variables match the conventional scores. We refer to these "adjusted" policies as ψ_t''. In practice, we choose a budget variable we want to match, and then adjust specific inputs within ψ_t so that the static estimates of that specific budget variable match the conventional estimates. In the example above where we increase the marginal tax rate on top earners, we would adjust the ordinary tax rate schedule, the deduction share, and the preferred tax rate schedule so that the static estimates of personal income tax matched the conventional estimates. Changes to one type of tax may have interaction effects on revenue from another type of tax. However, we usually ignore those interactions when making the adjustments. For example, changing personal income taxes may lead to changes in assets (because of changes to after-tax income), which leads

to a change in the estate tax revenues. Nonetheless, we typically do not adjust the estate tax schedule.[44]

In the next three subsections, we describe the three algorithms that we can use to adjust the inputs. These algorithms take a baseline policy ψ and a counterfactual or alternative policy ψ' and output an adjusted, alternative policy ψ'' that we use in the OLG model to simulate the effects of a counterfactual or alternative policy.

4.2.1 Convex Adjustments

One method we use to adjust policy inputs is a convex adjustment weight. We define a sequence of yearly values adj_t such that $\psi''_t = adj_t\psi'_t + (1 - adj_t)\psi_t$, where we slightly abuse the notation such that ψ_t are restricted to the specific government policies being adjusted, and all of the rest of the government policy inputs remain at their normal policy (ψ'_t) values.

This approach is useful for adjusting complicated schedules of variables such as tax rates. In the example above in which top marginal rates are increased, but lower-income filers are largely unaffected, any adjustments will effectively only apply to the higher-income households who end up affected by the changes to the top marginal rates.

4.2.2 Multiplicative Adjustments

The second method used to adjust inputs is a multiplicative adjustment factor. In this case, we define a sequence of yearly values adj_t such that $\psi''_t = adj_t\psi'_t$, again taking a shortcut with the notation such that ψ'_t are restricted to the specific government policies being adjusted.

This approach is useful for adjusting time-varying variables that are otherwise individual scalars. For example, consider a policy in which the federal government changes the level of money that it contributes to Medicaid. In order to hit federal targets for Medi-

[44] In practice, conventional estimates are not always available for other budget categories such as consumption or VAT taxes, which may be affected by changes to other types of statutory tax rates or brackets.

caid spending, the federal share of Medicaid spending may be scaled up or down so that the federal government contributions in the dynamic OLG model are consistent with the conventional estimates or statutory requirements of the policy proposal. In this case, adj_t scales both the federal share of Medicaid spending and the Medicaid income limit, expressed as a multiple of the federal poverty level, so the adjustment also changes which households are eligible. Its value is set such that static federal Medicaid outlays match the conventional estimates.

4.2.3 Additive Adjustments

The third method used to adjust the inputs is an additive adjustment factor. In this case, we define a sequence of yearly values adj_t such that $\psi_t'' = adj_t + \psi_t'$, again taking a short-cut with notation so that ψ_t' is restricted to the set of inputs being adjusted.

This algorithm is useful for matching budget variables and finding residuals needed to match aggregate indicators. For example, in our analysis, we may want to match the total primary deficit, in which case we would use an additive adjustment on an otherwise exogenous budget parameter. For example, if our budget deficit is $10 billion short of a conventional score of a large or complicated budget proposal, we may cut $10 billion from exogenous excise taxes which otherwise has no effect on the modeled economy, so that the static primary budget deficit matches the conventional estimate precisely. This $10 billion adjustment would show up in adj_t, which would be applied to the policy value for excise taxes.

4.3 Dynamic policy simulation

By contrast, the dynamic simulation satisfies all of the conditions in the competitive equilibrium. In this case, all prices, quantities, and choices are allowed to change relative to the baseline simulation. We construct all new household and firm policy schedules (Γ_h', $\{\Gamma_{b,j}'^f\}_{\{corp,pass\},\{1,\ldots,n\}}$, and Y_{T_0}') and a new, endogenously-determined household dis-

tribution (X'). In this model, the health insurers earn zero profits and all markets clear. The dynamic simulation captures all of the effects from new policies: the direct effects of the policies themselves, the effects from changing agent behavior, and the effects from changing factor prices.

5 Welfare

To examine the change in households' well-being, we use an Equivalent Variations (EV) measure of welfare. EV measures the amount by which a household's beginning-of-period assets would have to change in the baseline in order to make the household just as well off as under the policy.

Let $\Psi_t^{T_f} = \{p_i, \psi_i, X_i\}_{i=t}^{T_f}$ be the sequence of prices, government policies and household distributions in the baseline simulation, and let $\Psi_t'^{T_f} = \{p_i', \psi_i', X_i'\}_{i=t}^{T_f}$ be the corresponding sequence in the dynamic policy simulation (Section 4.3). As in Section 4, a prime marks a variable under the policy. The measure is calculated as follows:

For any state $s = (j, a, b, z, h, d, i)$, we compute the one-time wealth transfer $ev(s, \Psi_t'^{T_f})$ that yields as much welfare gain in the baseline economy as the policy change:

$$V(s, \Psi_t'^{T_f}) = V(\hat{s} = (j, a + ev(s, \Psi_t'^{T_f}), b, z, h, d, i), \Psi_t^{T_f}) \tag{86}$$

The left-hand side is the household's value under the policy, and the right-hand side is its value in the baseline after the transfer is added to its assets.

The function ev gives the one-time wealth transfer state-by-state. To report more aggregated measures of equivalent variation, for any subset $\tilde{S} \subset S$, we can compute:

$$AEV(\tilde{S}, \Psi_t'^{T_f}) \equiv \int_{\tilde{S}} ev(s, \Psi_t'^{T_f}) dX_t(s; \Psi_t^{T_f}) / \int_{\tilde{S}} dX_t(s; \Psi_t^{T_f}) \tag{87}$$

We can also compute measures of equivalent variation that are based on endogenous outcomes Γ in the baseline (e.g. compute EVs based on income quintiles). For any outcome, Γ, and any subset $\tilde{S} \subset S$, we can define the subset $S_\Gamma \equiv \{s \in \tilde{S} : \Gamma_h(s, p_t, \psi_t) \in \Gamma\}$ and then compute an EV measure for

$$AEV(S_\Gamma, \Psi_t'^{T_f}) = \int_{S_\Gamma} ev(s, \Psi_t'^{T_f}) dX_t(s; \Psi_t^{T_f}) / \int_{S_\Gamma} dX_t(s; \Psi_t^{T_f}). \tag{88}$$

In any comparison of a baseline and a policy simulation, the policy is announced at the beginning of the first transition year, $T_e = T_0 + 1$, because year T_0 is the initial steady state in both simulations. Prices under the policy, p'_t, can differ from baseline prices p_t for $t \geq T_e$, and the distributions of firm capital and of households, X'_t, can differ from their baseline values for $t = T_e + 1, \ldots, T_f$. The household distribution of year T_e is the same in both simulations, $X'_{T_e} = X_{T_e}$, because it results from choices made in year T_0. We therefore evaluate each cohort once, at the first date on which the policy affects it: households of every age in year T_e, and in each later year only the households that enter at age J_B. The aggregate measures (87) and (88) are computed for each year $t \geq T_e$ over the subset

$$\tilde{S}_t = \begin{cases} S, & t = T_e, \\ \{s \in S : j = J_B\}, & t > T_e, \end{cases} \tag{89}$$

with the baseline distribution $X_t(s; \Psi_t^{T_f})$ of that year as weights. The value $V(s, \Psi_{T_e}'^{T_f})$ of a cohort alive in year T_e already accounts for the whole path of prices and policies under the policy, so that cohort is not evaluated again in later years. We report each later cohort under the age it would have had in year T_e, $J_B - (t - T_e)$, which is below J_B because the cohort has not yet entered in year T_e. The age at which later cohorts are evaluated is a run setting: if it is set above J_B, the cohorts younger than that age in year T_e are each evaluated in the year they reach it.

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Appendixes

A The Value of Death

This appendix describes the value of death, ζ: how it enters the household problem, why the model needs it, which alternative specifications exist, how we calibrate it, and what it implies for interpreting the model and measuring welfare.

A.1 Specification

A household that dies at the end of a period receives the value of death ζ in place of its continuation value. For ages $j < J_D$, the household problem of Section 1.1.8 reads

$$V(s, \Psi_t^{t+J_D-j}) = \max_{c,l,a',i',\iota} \left\{ u(c,l) + \tilde{\beta} \Big[\delta_t(j,h)\, \mathbb{E}\big[V(s', \Psi_{t+1}^{t+J_D-j}) \,\big|\, s, \Gamma_h \big] + \big(1 - \delta_t(j,h)\big)\zeta \Big] \right\}, \quad (90)$$

subject to the constraints and laws of motion stated there. At the maximum age J_D, the household dies with certainty at the end of the period. Its value is then the maximized period utility, $\max\{u(c,l)\}$, with no death term. The discount factor

$$\tilde{\beta} \equiv \beta(1+\mu)^{\alpha(1-\gamma)}$$

applies to growth-adjusted utility: consumption is growth-adjusted by $(1+\mu)^{-t}$, and period utility in Equation (2) is homogeneous of degree $\alpha(1-\gamma)$ in consumption, so discounting growth-adjusted utility at $\tilde{\beta}$ is equivalent to discounting unadjusted utility at β. The death term is discounted in the same way as the continuation value because death occurs at the end of the period.

The value of death has the following properties:

- **Constant.** ζ is the same for every age, health state, insurance status, asset level, and

year, and it is the same in the baseline and in all policy simulations. Because it is defined in growth-adjusted utility units, it scales with productivity in the same way as period utility, which keeps the balanced growth path stationary.

- **Utility units.** ζ is measured in the units of u and V, not in dollars.
- **Negative.** $\zeta < 0$, for the reasons given in Section A.2.
- **Independent of savings.** ζ does not depend on the savings a' a household leaves behind. Households therefore have no bequest motive, and all bequests are accidental (Section 1.1.7).
- **Timing.** Death occurs at the end of the period, after all choices, with probability $1 - \delta_t(j, h)$, which depends on current health h. The care decision ι does not affect survival in the current period; it affects health next period, h', and therefore survival in later periods (Section 2.6.4).

A.2 Why the Model Needs a Value of Death

Because $\gamma > 1$, period utility in Equation (2) is negative for every combination of consumption and leisure. The value function, a discounted, survival-weighted sum of period utilities and death terms, is therefore negative as well. Let $\bar{V}(s) \equiv \mathbb{E}[V(s', \Psi_{t+1}^{t+J_D-j}) \,|\, s, \Gamma_h]$ denote the expected continuation value. Raising the survival probability $\delta_t(j, h)$ by Δ changes the right-hand side of Equation (90) by

$$\tilde{\beta}\, \Delta \left(\bar{V}(s) - \zeta \right),$$

so a household values survival only if its expected continuation value exceeds ζ. With $\zeta = 0$, every household would prefer death to survival, because its continuation value is negative.

In a model with exogenous health and survival, this would not affect behavior: the death terms would only shift the value function by amounts that no choice can influence, and ζ could be normalized to zero. In our model, households choose whether to pay for medical care, ι, and that choice affects next period's health and hence future survival. A household that forgoes care saves medical spending today but raises its probability of being in worse health, and thus of dying, in later periods. The value of death prices this trade-off. If ζ were too high, households would forgo care in order to shorten their lives. ζ must therefore be sufficiently negative that households have no incentive to seek an early death by forgoing treatment.

A.3 Alternative Specifications

A.3.1 Shifting Period Utility

Hall and Jones (2007) face the same problem and add a constant to period utility so that utility is positive and death, valued at zero, is worse than life (see their Equation (6), p. 47). That constant then determines the value of life. We keep the standard utility function and choose the value of death instead.

A.3.2 State-Dependent Value of Death

The value of death can be tied to the household's own expected continuation value, $\zeta A(s)$ with $A(s) \equiv \bar{V}(s)$ and $\zeta > 1$. Because $A(s) < 0$, $\zeta A(s) < A(s)$ in every state, so death is always worse than survival. If $A(s)$ is evaluated at the household's choices, the bracket in Equation (90) becomes $\left[\delta_t(j,h) + (1-\delta_t(j,h))\zeta\right]A(s)$. The specification then replaces the effective discount factor $\tilde{\beta}\delta_t(j,h)$ with $\tilde{\beta}\left[1 + (1-\delta_t(j,h))(\zeta-1)\right]$, which exceeds $\tilde{\beta}$ and rises as survival falls. Households with lower survival probabilities thus act as if they were more patient. In addition, the value of death changes whenever a policy changes continuation values, so it is no longer a fixed feature of preferences.

A.3.3 Bequest-Dependent Value of Death

The value of death can depend on the estate the household leaves, as in the joy-of-giving bequest motive of De Nardi (2004): $\zeta(a') = \zeta_0 + \zeta_1 v(a')$, where v is increasing and concave. With $\zeta_1 > 0$, households value what they leave behind and save more at old ages, and the additional parameters must be calibrated to the wealth holdings of the elderly. Our specification is the special case $\zeta_1 = 0$, in which the model has no bequest motive.

A.3.4 Our Choice: A Constant Value of Death

We use a constant ζ. It requires a single parameter, leaves period utility and the discount factor unchanged, introduces no bequest motive, and is identical in the baseline and in every policy simulation. Differences across simulations therefore reflect changes in survival probabilities and continuation values, not changes in the value of death itself. The limitation is that V varies with age, health, and resources while ζ does not, so a constant ζ does not by itself guarantee $\bar{V}(s) > \zeta$ in every state. We do not impose that inequality. Instead, we discipline ζ with the observed care decisions of the households whose survival is most at stake, as described next.

A.4 Calibration

We calibrate ζ so that the initial steady state matches the ratio of average medical spending of uninsured households to that of privately insured households aged 26 to 64 in the worst health state, $h = 5$:

$$R_5 = \frac{\int_{S_U} \iota(s)\, m(j,h,d)\, dX_{T_0}(s) \Big/ \int_{S_U} dX_{T_0}(s)}{\int_{S_P} \iota(s)\, m(j,h,d)\, dX_{T_0}(s) \Big/ \int_{S_P} dX_{T_0}(s)}, \tag{91}$$

where $\iota(s)$ is the household's care decision and $m(j, h, d)$ its medical expenditure, so that spending counts only when the household pays for care. The set S_U contains households aged 26 to 64 in health state 5 who are uninsured ($i = 0$) and not categorically eligible for Medicaid. The set S_P contains households aged 26 to 64 in health state 5 who are privately insured, excluding Medicare enrollees and households categorically eligible for Medicaid. The target, R_5^*, is from the Medical Expenditure Panel Survey, 2012–2022.

The value of death is the only parameter that can target this ratio. For health states 1 to 4, the parameters $\delta^{ht}(h)$ set the intensity with which forgoing care shifts health transitions toward worse states, and they target the corresponding spending ratios (Section 2.6.4). For $h = 5$, this instrument has no effect: households in the worst health state who forgo care remain in that state with certainty, whatever the value of $\delta^{ht}(5)$, which we therefore set to one. Because ζ also affects care decisions in health states 1 to 4, we calibrate ζ jointly with $\delta^{ht}(1), \ldots, \delta^{ht}(4)$.

A more negative ζ makes death more costly. Uninsured households in poor health then pay for more of their care, which raises R_5. In each iteration n of the calibration, we update ζ with a damped multiplicative step:

$$
\begin{aligned}
\bar{R}_5^{(n)} &= 0.65\, \bar{R}_5^{(n-1)} + 0.35\, R_5^{(n)}, \qquad \bar{R}_5^{(1)} = R_5^{(1)}, \\
x^{(n)} &= \min\left\{0.15,\ \max\left\{-0.15,\ \frac{R_5^* - \bar{R}_5^{(n)}}{R_5^*}\right\}\right\}, \\
\zeta^{(n+1)} &= \min\left\{\zeta^{(n)}\left(1 + 0.15\, x^{(n)}\right),\ -10^{-3}\right\},
\end{aligned}
$$

where $R_5^{(n)}$ is the model ratio in iteration n and $\bar{R}_5^{(n)}$ is its exponentially smoothed value. When the error $R_5^* - \bar{R}_5^{(n)}$ changes sign between iterations, we multiply $x^{(n)}$ by 0.35 to dampen oscillations. A model ratio below the target thus makes ζ more negative. The multiplicative step keeps the sign of ζ, and the cap at -10^{-3} keeps ζ strictly negative.

The calibrated value is $\zeta = -462.81$ (Table 2). At this value, the model ratio is 39 percent, compared with 38 percent in the data (Table 7).

A.5 Interpretation and Welfare

The value of death is measured in the same growth-adjusted utility units as V. Its level cannot be read as a dollar value of life. Behavior depends on ζ only through its position relative to the expected continuation values $\bar{V}(s)$, and translating utility into dollars requires a welfare measure such as the equivalent variation in Section 5.

Because ζ is a preference parameter, we hold it fixed across the baseline and policy simulations. A policy that changes survival, directly or through care decisions, changes the weight on the death term, and the resulting welfare effect scales with $\bar{V}(s) - \zeta$. A more negative ζ therefore raises the welfare value of policies that improve survival, such as policies that make medical care more affordable for the uninsured.

The wealth-based equivalent variation in Equation (86) compares value functions directly and does not require utility to be homothetic, so a constant ζ poses no problem for it. A consumption-equivalent measure is different. Scaling consumption by $1 + \lambda$ in every period and state, holding all decisions fixed, multiplies every period utility by $(1+\lambda)^{\alpha(1-\gamma)}$ but leaves the death terms unchanged. Let D^B denote the discounted, survival-weighted sum of the death terms along the baseline path, a component of the baseline value V^B. The consumption-equivalent variation λ that makes the baseline as valuable as the policy, V^P, then solves

$$V^P = (1+\lambda)^{\alpha(1-\gamma)}\left(V^B - D^B\right) + D^B.$$

The familiar closed form $\lambda = (V^P/V^B)^{1/(\alpha(1-\gamma))} - 1$ holds exactly only when $D^B = 0$, and it is accurate only where D^B is small relative to V^B.

B The Model Economy with Multiple Demographic Groups

This appendix extends the model of Section 1 to multiple demographic groups. Distinguishing groups allows the model to represent differences in policy (for example, tax rules for single and married households), in economic conditions (for example, wages and employment), and in demographic processes (for example, fertility and mortality).

Households are partitioned into a finite set of groups, $\mathcal{G}$. Households in different groups supply different types of labor, earn different wages, face different demographic flows, and may be subject to different policy rules; otherwise, they solve the same household problem. The model of Section 1 is the special case $|\mathcal{G}| = 1$, in which a single group contains every household. We describe the general case as a set of modifications to Section 1; all elements not discussed here are unchanged.

We implement two versions of the extension. In the six-group model, described in Sections B.1–B.5, households are classified by three skill types (low-educated, high-educated non-STEM, and high-educated STEM) and two nativity classes (U.S.-born and foreign-born). The nine-group model, described in Section B.6, further divides each foreign-born group by arrival cohort.

We have used this extension to analyze immigration policy. Arnon et al. (2026) use the six-group model to study the effects of exempting STEM immigrants from the employment-based green card cap and the per-country limit on output, the federal budget, and the earnings and welfare of each worker type. In that analysis, the effect of immigration on wages depends on the elasticity of substitution between new arrivals and the workers already in the economy and on the response of total factor productivity to STEM employment. The model therefore distinguishes workers by education, STEM occupation, and nativity, and, within each group, by experience; total factor productivity is a function of STEM employment.

[cite new bundles brief] studies an increase in immigration as part of a reform package

that reduces federal debt and increases output. The package requires new immigrants to purchase private health insurance without federal subsidy and excludes them from Medicaid and ACA premium subsidies, while immigrants already in the United States remain under current-law rules. The nine-group model accommodates this distinction because it separates foreign-born households by arrival cohort.

B.1 Groups and Notation

B.1.1 Skill types

Skill types are defined by educational attainment and occupation. Non-college workers (NC) do not hold a bachelor's degree. College-educated workers hold a bachelor's degree or higher and are further divided by occupation into those in STEM occupations (CS) and those in non-STEM occupations (CNS).[45] We use $k \in \{\mathrm{NC}, \mathrm{CNS}, \mathrm{CS}\}$ to denote a generic skill type.

B.1.2 Nativity

Households are either U.S.-born (US) or foreign (F).[46]

B.1.3 Groups

In the six-group model, the set of groups is

$$\mathcal{G}^6 = \{\mathrm{NC},\ \mathrm{CNS},\ \mathrm{CS}\} \times \{\mathrm{US},\ \mathrm{F}\},$$

and we index groups by $g \in \mathcal{G}$, so that (k, US) and (k, F) are the U.S.-born and foreign-born of skill type k. Each household's education, occupation, and nativity, and therefore

[45] STEM occupations follow the 2010 Standard Occupational Classification (SOC) Policy Committee definition, as in Arnon et al. (2026).

[46] U.S.-born households are native-born U.S. citizens. Foreign households are all others: naturalized citizens, lawful noncitizens, and unauthorized immigrants.

its group, are assigned by Penn Wharton Budget Model's Microsim, which supplies all demographic inputs to the model.

Each group has its own measure of households X_t^g, value function V^g, decision rules Γ_h^g, and demographic flows, all of which carry a superscript g. Groups also differ in the wages they earn (Section B.2.1) and in household size, that is, in the number of adults $\Omega_{a,t}^g(j)$ and children $\Omega_{c,t}^g(j)$, which affects several parts of the household problem (Section B.2.2). Survival probabilities are group-specific (Section B.2.4), and the production side adds the parameters listed in Table 17. Preference parameters, the labor productivity function $e(j, h, z)$ and the process for ability z (its transition probabilities π_z and initial distribution π_z^0), the medical expenditures of household heads and children estimated from the data, baseline health transition probabilities, asset returns, and the tax, transfer, and insurance rules are the same for all groups in the baseline. An immigration policy may also impose group-specific rules (see Section B.6).

B.1.4 Education-level pools

Some objects are computed from the distribution of households over states. For some groups, ages, and years, that distribution is very thin or even empty, so these objects are computed with data pooled across groups with the same education level. We denote by $\mathcal{P}(g)$ the education-level pool of group g. In the six-group model, the two education-level pools are the non-college groups and the college-educated groups,

$$\big\{(\mathrm{NC}, \mathrm{US}),\ (\mathrm{NC}, \mathrm{F})\big\} \quad \text{and} \quad \big\{(\mathrm{CNS}, \mathrm{US}),\ (\mathrm{CNS}, \mathrm{F}),\ (\mathrm{CS}, \mathrm{US}),\ (\mathrm{CS}, \mathrm{F})\big\}.$$

Education-level pools are used for the medical expenditures of additional adults (Section B.2.3) and for survival probabilities (Section B.2.4).

B.1.5 Experience

Wages also vary with labor market experience. We group workers into nine experience brackets, $v \in \{1, \ldots, 9\}$, corresponding to 1–5, 6–10, …, 41–45 years of potential experience. In the model, potential experience is approximated by age, so that a household of age j is in bracket

$$v(j) = \min\left\{\left\lfloor \frac{j - J_B}{5} \right\rfloor + 1,\ 9\right\}.$$

where $J_B = 21$ is the age at which households enter the model. Brackets 1 through 8 each span five years of age from 21 to 60, and bracket 9 contains all ages from 61 onward.[47] Brackets are assigned by age alone and do not depend on a household's education or work history.

B.2 Households

The household problem of Section 1.1.8 is unchanged in form. Each group solves it with its own value function V^g and decision rules Γ_h^g, and the elements listed in Section B.1 as common to all groups enter every group's problem in the same way. The private insurance premium $p_{p,t}(j)$ of equation (27) is computed from the enrollment of all groups combined and applies to every group.

From the household's point of view, group membership is permanent. The expectation in equation (10) is taken over next period's state within the same group, so that the problem of a group-g household is

$$V^g(s, \Psi_t^{t+J_D-j}) = \max_{c,l,a',i',\iota} \left\{ u(c,l) + \beta\, \mathbb{E}\left[\delta_t^g(j,h)\, V^g(s', \Psi_{t+1}^{t+J_D-j-1}) \,\middle|\, s, \Gamma_h^g \right] + \left(1 - \delta_t^g(j,h)\right)\zeta \right\}, \tag{92}$$

with the continuation value given by the same group's value function V^g. Households do not anticipate moving to another group, even though some households do so in the data.

[47] Bracket 9 is not a retirement bracket. Retired households supply no labor and therefore do not enter the labor aggregates below.

These moves are accounted for only at the aggregate level, in the law of motion of the distribution (Section B.3): the mass of households that switch is removed from the origin group and added to the destination group, where it follows that group's decision rules from then on. This assumption also simplifies the computation: given prices and policies, each group's problem is solved separately.

Households in different groups differ in the following respects. Each of them enters the household problem (92) directly: wages and household size determine labor income, the time endowment, and other terms in the budget constraint; medical expenditures enter the budget constraint through out-of-pocket spending and also affect health transitions, and therefore future survival; survival probabilities determine the weight on the continuation value; and inheritances enter cash on hand.

B.2.1 Wages

Each group faces its own wage, which also depends on the household's experience bracket and is determined in Section B.5. Wages differ across groups and experience brackets because their labor inputs are imperfect substitutes in production (Section B.5.1). Gross labor income becomes

$$y_t^{G,g}(j,h,z,l) = w^g_{v(j),t}\, e(j,h,z)\left(\Omega^g_{a,t}(j)\, l_{\max} - l\right), \tag{93}$$

which replaces $w_t\, e(j,h,z)\left(\Omega_{a,t}(j)\, l_{\max} - l\right)$ in Section 1.1.8. The labor productivity function $e(j,h,z)$ is common to all groups, so two households in the same state but in different groups differ in their earnings only through wages and household size. Average earnings by group also depend on each group's distribution over states and on its labor supply choices.

B.2.2 Household size

The number of adults $\Omega^g_{a,t}(j)$ and children $\Omega^g_{c,t}(j)$ per household is group-specific. It replaces $\Omega_{a,t}(j)$ and $\Omega_{c,t}(j)$ wherever they appear in Section 1. As a result, household size affects:

- the time endowment, $\Omega^g_{a,t}(j)\, l_{\max}$, where the maximum leisure hours per adult, $l_{\max}$, are the same for all groups;
- private insurance and Medicare premiums, which are paid for each adult;
- medical expenditures, since a larger household has more members whose medical costs it must pay (Section B.2.3);
- the health transitions of households that forgo medical care, which depend on the household's medical expenditures;
- eligibility for means-tested programs, such as Medicaid and SNAP, whose income thresholds increase with family size;
- the earnings history used to compute OASI benefits, which is measured per adult.

B.2.3 Medical expenditures

Household medical expenditures are computed as in Section 2.6, with group-specific household size,

$$m^g(j,h,d) = m^H(j,h,d) + \left(\Omega^g_a(j) - 1\right) m_t^{S,\mathcal{P}(g)}(j) + \Omega^g_c(j)\, m^C. \tag{94}$$

The medical expenditures of the household head, $m^H(j,h,d)$, and of each child, m^C, are estimated from MEPS data (Section 2.6) and are the same for all groups. The expenditure of each additional adult, $m_t^{S,\mathcal{P}(g)}(j)$, is the average expenditure of household heads of age j, weighted by the model's distribution of households over health states and expenditure

levels. For some groups, ages, and years, that distribution is very thin or empty, in particular for the foreign groups, and especially the college-educated ones. The average would then be poorly defined, and setting it to zero would understate household expenditures and distort the health transitions described below. We therefore compute the average over the distribution of the education-level pool $\mathcal{P}(g)$ (Section B.1.4),

$$m_t^{S,\mathcal{P}(g)}(j) = \sum_{h,d} \omega_{j,h,d,t}^{\mathcal{P}(g)} \, m^H(j,h,d), \tag{95}$$

where $\omega_{j,h,d,t}^{\mathcal{P}(g)}$ is the share of households of age j in the groups of pool $\mathcal{P}(g)$ that are in health state h and expenditure level d, so that $\sum_{h,d} \omega_{j,h,d,t}^{\mathcal{P}(g)} = 1$. All groups in the same pool therefore share the same $m_t^{S,\mathcal{P}(g)}(j)$.

B.2.3.1 Health transitions

Health transitions are group-specific for households that forgo medical care. For these households, the probability of moving to a worse health state depends on their medical expenditures relative to the lowest expenditure level, $m^g(j,h,d)/m^g(j,h,1)$, which differs across groups through household size and $m_t^{S,\mathcal{P}(g)}(j)$. For households that receive care, health transitions are the baseline probabilities $\pi_h(h'|j,h)$ and are the same for all groups.

B.2.4 Survival

Survival probabilities $\delta_t^g(j,h)$ determine the weight on the continuation value in equation (92) and are group-specific. They are computed with the same approach as in Section 2.6.4, adjusting the health-specific survival probabilities so that, on average across health states, they match the Microsim survival rates by age. Equations (78) and (79) be-

come

$$\sum_h \omega_{j,h,t}^{\mathcal{P}(g)} \left(1 - \delta_{j,h}^{\text{MEPS}}\right)^{\varphi_{j,t}^g} = 1 - \delta_{j,t}^{\text{microsim},\mathcal{P}(g)}, \tag{96}$$

$$\delta_t^g(j,h) = 1 - \left(1 - \delta_{j,h}^{\text{MEPS}}\right)^{\varphi_{j,t}^g}, \tag{97}$$

where $\omega_{j,h,t}^{\mathcal{P}(g)}$ is the share of households of age j in the groups of pool $\mathcal{P}(g)$ that are in health state h, so that $\sum_h \omega_{j,h,t}^{\mathcal{P}(g)} = 1$. The weights and the target death rate are computed over the education-level pool $\mathcal{P}(g)$ rather than over group g alone (Section B.1.4). Pooling is needed because some groups have very few households, and therefore very few deaths, at some ages and in some years, which is not enough to pin down their survival rates. As a result, all groups in the same education-level pool have the same survival probability at each age and health state. For example, a non-college household aged 40 in a given health state has the same probability of surviving whether it is U.S.-born or foreign. Groups in the same pool can still differ in their average mortality at a given age, because their members can be distributed differently across health states.

As in Section 2.6.4, survival probabilities are computed only in the baseline, and policy simulations use the baseline survival probabilities, even if a policy changes the distribution of households across health states.

B.2.5 Bequests

Bequests and inheritances work as in Section 1.1.7, but separately for each group: the bequests left by deceased households of group g are distributed only to living households of the same group. Group g therefore has its own inheritance pool Q_t^g, defined as Q_t in Section 1.1.7 with δ_t and X_t replaced by δ_t^g and X_t^g. A household of group g with age j and ability z receives the inheritance

$$inh_t^g(j,z) = \omega^q(j,z) \left(\int_s \omega^q(j,z)\, dX_t^g(s) \right)^{-1} Q_t^g, \tag{98}$$

as in equation (9), so that the inheritances received by all households of group g sum to the group's pool Q_t^g. The parameters $\omega^q(j,z)$ set how large the inheritance is at each age and ability level relative to others, following the profiles from the Survey of Consumer Finances described in Section 2.5. They are the same for all groups, so groups differ only in the size of their pool and in the distribution of their members across ages and ability levels.

B.3 The Distribution of Households

As in Section 1.2, each group has its own measure of households X_t^g, which evolves through exogenous flows taken from Microsim. Households enter group g in three ways: by entering the model at age J_B, by immigrating, or by moving from another group. They leave it in three ways: by dying, by emigrating, or by moving to another group. Entry at age J_B, immigration, death, and emigration work as in the main model, with group-specific flows. Moves between groups are the only new element.

An immigration policy is implemented in Microsim and changes these group-specific flows. Its most direct effect is on the immigrant inflows $im_t^{(k,\mathrm{F})}(j)$ into the foreign groups. Through the spouses and children of additional immigrants, it also changes, in later years, the entrants at age J_B and the moves between groups, including for U.S.-born groups.

B.3.1 Entrants at age J_B

Households entering the model at age J_B are treated as in Section 1.2.1, with two differences. First, the mass of each group at age J_B is set to that group's population at that age in Microsim. Second, the initial distribution over (z, h, d) is the same for all groups, obtained by pooling the initial distributions of all groups. As in the main model, entrants start with $a = 0$ and $b = 0$ (equation (20)), and their initial insurance status is chosen following Steps 1–3 of Section 1.2.1, with V_t replaced by the value function of their own group, V_t^g.

B.3.2 Immigration and emigration

Immigrants are placed in the state space as in Section 1.2.1: an immigrant of age j entering group g takes the distribution of residents of the same age in that group, $\pi_t^{\text{immi},g}(\cdot \mid j)$, given by equation (22) with $\tilde{X}_t$ replaced by the measure of group g, $\tilde{X}_t^g$, and with the same fallbacks when the group has no residents at that age. The number of immigrants, $im_t^g(j)$, comes from Microsim. Emigration also works as in the main model, at the group-specific rate $em_t^{\text{rate},g}(j) = em_t^g(j)/\hat{x}_t^{\text{microsim},g}(j)$, where $\hat{x}_t^{\text{microsim},g}(j)$ is the Microsim population of group g at age j in period t.

B.3.3 Moves between groups

Unlike in the main model, households can also move from one group to another. In each period, an exogenous mass $tr_t^{g' \to g}(j)$ of age-j households leaves group g' for group g. These flows come from Microsim and mostly reflect changes in educational attainment and occupation, such as completing a bachelor's degree or moving into or out of a STEM occupation; no household in the model chooses its group, and, as discussed in Section B.2, households do not anticipate these moves when solving their problem (92). We denote total inflows and outflows by

$$tr_t^{\text{in},g}(j) = \sum_{g' \neq g} tr_t^{g' \to g}(j), \qquad tr_t^{\text{out},g}(j) = \sum_{g' \neq g} tr_t^{g \to g'}(j).$$

B.3.3.1 Leaving a group

As with emigration, households leave a group at a flat rate within each age, $tr_t^{\text{out,rate},g}(j) = tr_t^{\text{out},g}(j)/\hat{x}_t^{\text{microsim},g}(j)$, which does not depend on health or any other state variable. The adjusted survival probability of equation (23) is therefore computed for each group g, net

of both emigration and moves to other groups:

$$\tilde{\delta}_t^g(j,h) = \max\left\{0,\ \delta_t^g(j,h) - em_t^{\text{rate},g}(j) - tr_t^{\text{out,rate},g}(j)\right\}. \tag{99}$$

The flows and the population that defines the rates are taken from the same year and age, so that the combined exit rate cannot exceed one.

B.3.3.2 Arriving in a group

We call households that move from one group to another *switchers*. Microsim provides only the number of switchers by origin group, destination group, and age, not their assets, earnings history, ability, health, or insurance status. The model therefore needs a rule to place arriving switchers in the state space. We assume that switchers arriving in a group look like the households of the groups they come from.

To state this rule, let $\pi_t^g(\cdot \mid j)$ be the share of age-j households of group g in each state (a, b, z, h, d, i) at the beginning of period t; that is, the measure of group g at age j divided by its total mass at that age, so that the shares sum to one. The distribution of switchers arriving in group g at age $j+1$, $\pi_t^{\text{sw},g}(\cdot \mid j+1)$, combines the distributions of their origin groups, with each origin group g' counted in proportion to the number of switchers it sends to g:

$$\pi_t^{\text{sw},g}(\cdot \mid j+1) = \frac{\sum_{g' \neq g} tr_t^{g' \to g}(j)\, \pi_t^{g'}(\cdot \mid j+1)}{\sum_{g' \neq g} tr_t^{g' \to g}(j)}. \tag{100}$$

For example, if 100 households of age 30 move into group g from group g_1 and 20 from group g_2, five sixths of the arriving switchers are distributed like the 31-year-olds of g_1 and one sixth like the 31-year-olds of g_2. The origin distributions are taken at age $j+1$ because switchers who move at age j arrive in their new group one year older. As a result, switchers keep the wealth and earnings history typical of the group they leave, rather than taking on those of their new group. In the law of motion (103), the mass of arriving switchers, $tr_t^{\text{in},g}(j)$, is added to group g at age $j+1$ with distribution $\pi_t^{\text{sw},g}$. If no origin

group has households at that age, switchers take the destination group's own distribution instead.

B.3.4 Scaling vector and law of motion

As in Section 1.2.3, a scaling vector keeps the model's population by age consistent with Microsim, but it is now computed separately for each group. Let $\hat{x}_t^{\text{microsim},g}(j)$ denote the Microsim population of group g at age j in period t, and let $de_t^g(j)$, $em_t^g(j)$, and $im_t^g(j)$ denote the group's Microsim numbers of deaths, emigrants, and immigrants. Equation (24) becomes, for each group g,

$$\hat{x}_{t+1}^{\text{forecast},g}(j+1) = \hat{x}_t^{\text{microsim},g}(j) - de_t^g(j) - em_t^g(j) - tr_t^{\text{out},g}(j) + tr_t^{\text{in},g}(j) + im_{t+1}^g(j+1), \quad (101)$$

which adds to equation (24) the households that move out of and into group g. The scaling vector of group g is then given by equation (25) with the group's own populations,

$$\pi_{t+1}^{s,g}(j) = \frac{\hat{x}_{t+1}^{\text{microsim},g}(j)}{\hat{x}_{t+1}^{\text{forecast},g}(j)}. \quad (102)$$

Each group therefore has its own scaling vector, which, as in the main model, depends only on Microsim data and is computed once for each year.

The law of motion (26) becomes, for each group g and for $j = J_B, \ldots, J_D - 1$,

$$\begin{aligned} x_{t+1}^g(s') = \pi_{t+1}^{s,g}(j') \Bigg[\int_S & \mathbf{1}_{\{a'=a'(),b'=b'(),h'=h'(),i'=i'()\}} \, \tilde{\delta}_t^g(j,h) \\ & \times \pi_z(z'|z)\, \pi_h(h'|j,h,d,\iota())\, \pi_d(d')\, dX_t^g(s) \\ & + \pi_{t+1}^{\text{immi},g}(s' \mid j')\, im_{t+1}^g(j') + \pi_t^{\text{sw},g}(s' \mid j')\, tr_t^{\text{in},g}(j) \Bigg], \end{aligned} \quad (103)$$

where $j' = j + 1$ and the indicator function is given by the group's own decision rules Γ_h^g. As in equation (26), inside the brackets the integral moves the surviving households of

group g forward, now using the group's adjusted survival probabilities $\tilde{\delta}_t^g(j,h)$ of equation (99), and the term $\pi_{t+1}^{\text{immi},g}(s' \mid j')\, im_{t+1}^g(j')$ adds the group's immigrants (Section B.3). The new term, $\pi_t^{\text{sw},g}(s' \mid j')\, tr_t^{\text{in},g}(j)$, adds the switchers arriving in group g, distributed as in equation (100). Immigrant inflows are indexed by the age at arrival, j', while switcher inflows are indexed by the age in the origin group, j; both arrive at age j'. The group's own scaling vector $\pi_{t+1}^{s,g}(j')$ then rescales the sum so that the population of group g at each age matches Microsim. The distribution of each group is rescaled only by its own scaling vector. Households of age J_B enter each group as described in Section B.3.

B.4 Aggregation

Aggregation follows Section 1.6. Wealth and medical expenditures are summed over groups, while labor is kept separate by group and experience bracket. Distributional statistics, such as the Gini coefficients of earnings and income, are computed for the economy as a whole, over the combined distribution of all households.

B.4.1 Wealth, capital, and medical expenditures

Private wealth and medical expenditures are the sums of the corresponding totals of each group,

$$A_{t+1} = \sum_{g \in \mathcal{G}} \int_S a'\, dX_t^g(s), \qquad M_t = \sum_{g \in \mathcal{G}} \int_S \frac{\iota \cdot m_t^g(j,h,d,i,X_t)}{1-\kappa_i}\, dX_t^g(s),$$

where m_t^g are the household medical expenditures of group g, which depend on the group's household size (Section B.2.3). The capital stock K_{t+1} follows from A_{t+1} as in Section 1.6.

B.4.2 Labor by group and experience

In the main model, aggregate labor L_t is the sum of the efficiency units of labor supplied by all households. With multiple groups, workers of different groups and experience levels are different inputs in production: they are imperfect substitutes, so an additional hour of one type of labor does not have the same effect on output as an additional hour of another. Labor is therefore not simply summed across groups; Section B.5 describes how the different inputs are combined into aggregate labor. As a first step, the model keeps track of the labor supplied by each group g in each experience bracket v,

$$L^g_{v,t} = \int_S \mathbf{1}_{\{v(j)=v\}}\, e(j,h,z)\big(\Omega^g_{a,t}(j)\, l_{\max} - l^g(s, \Psi_t^{t+J_D-j})\big)\, dX^g_t(s). \tag{104}$$

In words, $L^g_{v,t}$ is the total number of efficiency units of labor supplied in period t by the households of group g whose age falls in experience bracket v. For each of these households, hours worked, $\Omega^g_{a,t}(j)\, l_{\max} - l^g$, are multiplied by labor productivity, $e(j,h,z)$, and the result is summed over the distribution of group g; the indicator $\mathbf{1}_{\{v(j)=v\}}$ selects the households in bracket v. In the six-group model there are $6 \times 9 = 54$ such labor inputs. Section B.5 combines them into aggregate labor L_t through a nested CES aggregate and derives the wage of each input, w^g_v, as its marginal product.

B.5 Production

Production is the part of the model that changes the most when households are divided into groups. The firm sector is as described in Section 1.4, with two changes. First, workers of different groups and experience levels are imperfect substitutes in production: aggregate labor L_t is a nested CES aggregate of the labor supplied by each group and experience bracket, $L^g_{v,t}$ (Section B.5.1). This assumption is the key element of the extension. It implies that the wage of each type of worker depends on the composition of the labor force, so that, for example, additional immigrants of a given skill type affect the wages of

U.S.-born and foreign workers differently. Second, total factor productivity depends on the size of the college-educated STEM population (Section B.5.2). Section B.5.3 derives the resulting wages, and Section B.5.4 lists the parameters that the model with heterogeneous worker types adds to the model of Section 1, all of which enter the production side.

B.5.1 Labor aggregation

We suppress the time subscript. The nest has four levels and follows Arnon et al. (2026), with broader distinctions at the top and finer ones at the bottom. At each level, the inputs are imperfect substitutes, combined with a constant elasticity of substitution σ. Figure 10 shows the hierarchy.

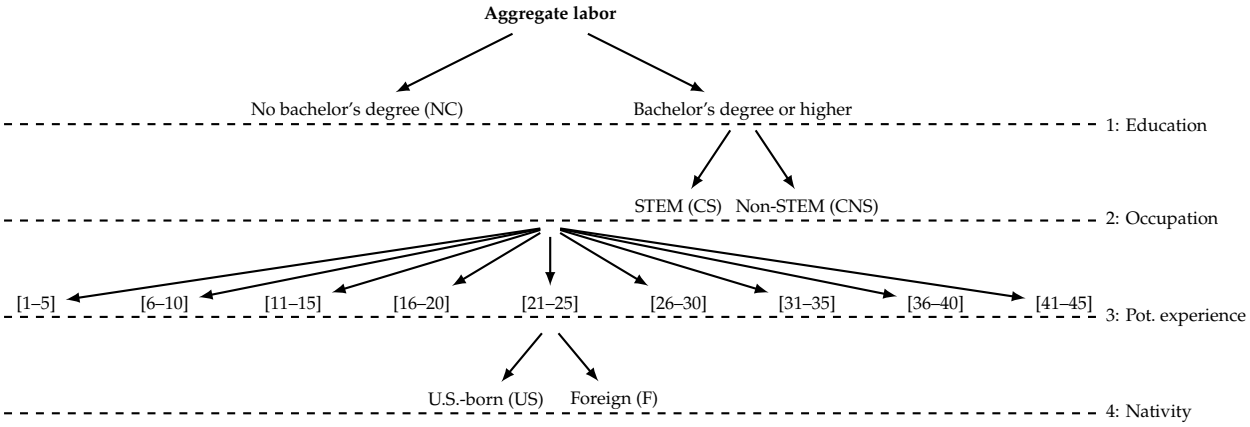


Figure 10: Labor aggregation hierarchy across education, STEM occupation, potential experience, and nativity

Source: Adapted from Arnon et al. (2026).

The top-level nest aggregates college-educated (C) and non-college (NC) labor into aggregate labor:

$$L = \left[\varpi_{\mathrm{C}} \, L_{\mathrm{C}}^{\frac{\sigma_{\mathrm{COL}}-1}{\sigma_{\mathrm{COL}}}} + \varpi_{\mathrm{NC}} \, L_{\mathrm{NC}}^{\frac{\sigma_{\mathrm{COL}}-1}{\sigma_{\mathrm{COL}}}} \right]^{\frac{\sigma_{\mathrm{COL}}}{\sigma_{\mathrm{COL}}-1}}, \tag{105}$$

where σ_{COL} is the elasticity of substitution between college-educated and non-college workers, and ϖ_{C} and ϖ_{NC} are efficiency parameters. The second level aggregates the two types of college-educated workers, those in STEM occupations (CS) and those in non-

STEM occupations (CNS):

$$L_{\mathrm{C}} = \left[\varpi_{\mathrm{CS}} \, L_{\mathrm{CS}}^{\frac{\sigma_{\mathrm{STEM}}-1}{\sigma_{\mathrm{STEM}}}} + \varpi_{\mathrm{CNS}} \, L_{\mathrm{CNS}}^{\frac{\sigma_{\mathrm{STEM}}-1}{\sigma_{\mathrm{STEM}}}} \right]^{\frac{\sigma_{\mathrm{STEM}}}{\sigma_{\mathrm{STEM}}-1}}, \tag{106}$$

where σ_{STEM} is the elasticity of substitution between college-educated workers in STEM and non-STEM occupations, and ϖ_{CS} and ϖ_{CNS} are efficiency parameters. The third level aggregates, within each skill type k, the nine experience brackets:

$$L_k = \left[\sum_{v=1}^{9} \varpi_{k,v} \, L_{k,v}^{\frac{\sigma_{\mathrm{EXP},k}-1}{\sigma_{\mathrm{EXP},k}}} \right]^{\frac{\sigma_{\mathrm{EXP},k}}{\sigma_{\mathrm{EXP},k}-1}}, \qquad k \in \{\mathrm{NC}, \mathrm{CNS}, \mathrm{CS}\}, \tag{107}$$

where $\sigma_{\mathrm{EXP},k}$ is the elasticity of substitution between experience brackets and $\varpi_{k,v}$ are efficiency parameters, both specific to skill type k. The final level distinguishes workers by nativity, aggregating U.S.-born (US) and foreign (F) labor within each skill type k and experience bracket v:

$$L_{k,v} = \left[\varpi_{k,\mathrm{US}} \left(L_v^{k,\mathrm{US}}\right)^{\frac{\sigma_{\mathrm{NAT},k}-1}{\sigma_{\mathrm{NAT},k}}} + \varpi_{k,\mathrm{F}} \left(L_v^{k,\mathrm{F}}\right)^{\frac{\sigma_{\mathrm{NAT},k}-1}{\sigma_{\mathrm{NAT},k}}} \right]^{\frac{\sigma_{\mathrm{NAT},k}}{\sigma_{\mathrm{NAT},k}-1}}, \tag{108}$$

where $L_v^{k,\mathrm{US}}$ and $L_v^{k,\mathrm{F}}$ are the labor supplies of equation (104) for the U.S.-born and foreign groups of skill type k, $\sigma_{\mathrm{NAT},k}$ is the elasticity of substitution between U.S.-born and foreign workers of skill type k, and $\varpi_{k,\mathrm{US}}$ and $\varpi_{k,\mathrm{F}}$ are efficiency parameters. We assume that both the elasticity $\sigma_{\mathrm{NAT},k}$ and the efficiency parameters $\varpi_{k,\mathrm{US}}$ and $\varpi_{k,\mathrm{F}}$ vary by skill type but not by experience bracket.

In all four levels, the efficiency parameters multiply the labor inputs raised to the power $(\sigma - 1)/\sigma$, rather than entering as $\varpi^{1/\sigma}$; the calibrated values of the efficiency parameters refer to this form.

B.5.2 STEM population and productivity

Total factor productivity in each sector rises with the size of the college-educated STEM population, $N_{\text{CS},t}$. We measure $N_{\text{CS},t}$ as the total number of households in the college-educated STEM groups, summed over both nativity classes and over all ages, so that it includes households that do not work, such as retirees. The productivity term $A_{j,t}$ of Section 1.4.2 becomes

$$A_{j,t} = \bar{A}_{j,t}\, N_{\text{CS},t}^{\chi}, \tag{109}$$

where $\bar{A}_{j,t}$ is the exogenous component and $\chi \geq 0$ is the elasticity of TFP with respect to the STEM population. Because individual firms take $N_{\text{CS},t}$ as given, the externality is not internalized: STEM workers are paid according to their private marginal product, net of business taxes as in equation (38), which excludes their effect on TFP.

B.5.3 Wages

Let w be the wage per unit of aggregate labor L. It is the same wage as in the main model, given by equation (38): the marginal product of aggregate labor, net of business taxes, deductions, and credits. With multiple groups, each labor input earns w times its marginal contribution to aggregate labor. Because each CES aggregate is homogeneous of degree one, the wage of group g in experience bracket v is

$$w_v^g = w\, \frac{\partial L}{\partial L_v^g}, \tag{110}$$

which is the group-specific version of equation (38). For non-college U.S.-born workers, this is

$$w_v^{\text{NC,US}} = w\, \omega_{\text{NC}} \left(\frac{L}{L_{\text{NC}}}\right)^{\frac{1}{\sigma_{\text{COL}}}} \omega_{\text{NC},v} \left(\frac{L_{\text{NC}}}{L_{\text{NC},v}}\right)^{\frac{1}{\sigma_{\text{EXP,NC}}}} \omega_{\text{NC,US}} \left(\frac{L_{\text{NC},v}}{L_v^{\text{NC,US}}}\right)^{\frac{1}{\sigma_{\text{NAT,NC}}}}, \tag{111}$$

and for college-educated workers it includes the additional STEM/non-STEM level; for example,

$$w_v^{\mathrm{CNS,US}} = w\ \varpi_{\mathrm{C}}\left(\frac{L}{L_{\mathrm{C}}}\right)^{\frac{1}{\sigma_{\mathrm{COL}}}} \varpi_{\mathrm{CNS}}\left(\frac{L_{\mathrm{C}}}{L_{\mathrm{CNS}}}\right)^{\frac{1}{\sigma_{\mathrm{STEM}}}} \times \varpi_{\mathrm{CNS},v}\left(\frac{L_{\mathrm{CNS}}}{L_{\mathrm{CNS},v}}\right)^{\frac{1}{\sigma_{\mathrm{EXP,CNS}}}} \varpi_{\mathrm{CNS,US}}\left(\frac{L_{\mathrm{CNS},v}}{L_v^{\mathrm{CNS,US}}}\right)^{\frac{1}{\sigma_{\mathrm{NAT,CNS}}}}. \tag{112}$$

The remaining wages follow the same pattern. The six-group model therefore has $6 \times 9 = 54$ wages. Each wage falls as the relative supply of its own labor type rises, and the elasticities $\sigma_{\mathrm{NAT},k}$ govern how strongly additional foreign workers depress the wages of U.S.-born workers with the same skill and experience. All wages also rise with TFP through w, so a larger STEM population raises the wages of every group through equation (109).

B.5.4 New parameters

The extension adds new parameters only to the production side of the model. On the household side, groups differ through their demographic inputs from Microsim, such as demographic flows and household size (Sections B.2 and B.3), but not through additional parameters. Table 17 lists the parameters that the six-group model adds to the model of Section 1: the efficiency parameters and elasticities of substitution of the labor nest (Section B.5.1) and the elasticity of total factor productivity with respect to the STEM population (Section B.5.2). The estimation of the elasticities of substitution and the calibration of the efficiency parameters are described in detail in Arnon et al. (2026).

B.6 The Nine-Group Model

The nine-group model splits each foreign group by arrival cohort:

$$\mathcal{G}^9 = \{\mathrm{NC},\ \mathrm{CNS},\ \mathrm{CS}\} \times \{\mathrm{US},\ \mathrm{F}^{\mathrm{old}},\ \mathrm{F}^{\mathrm{new}}\},$$

Table 17: Parameters of the model with heterogeneous worker types

Parameter	Description	Equation
ϖ_{C}, ϖ_{NC}	College and non-college efficiency	(105)
σ_{COL}	Elasticity of substitution, college vs. non-college	(105)
ϖ_{CS}, ϖ_{CNS}	STEM and non-STEM efficiency	(106)
σ_{STEM}	Elasticity of substitution, STEM vs. non-STEM	(106)
$\varpi_{k,v}$	Experience-bracket efficiency, skill type k	(107)
$\sigma_{\mathrm{EXP},k}$	Elasticity of substitution across experience brackets	(107)
$\varpi_{k,\mathrm{US}}$, $\varpi_{k,\mathrm{F}}$	U.S.-born and foreign efficiency, skill type k	(108)
$\sigma_{\mathrm{NAT},k}$	Elasticity of substitution, U.S.-born vs. foreign	(108)
χ	Elasticity of TFP with respect to the STEM population	(109)

where $\mathrm{F}^{\mathrm{old}}$ denotes foreign households who arrived before a cutoff year set in Microsim and $\mathrm{F}^{\mathrm{new}}$ those who arrive after it. We refer to $\mathrm{F}^{\mathrm{old}}$ and $\mathrm{F}^{\mathrm{new}}$ as the two foreign cohorts. This distinction allows immigration policy to act on new arrivals while leaving the existing foreign population unaffected. Section B.6.1 describes the household side of the nine-group model, Section B.6.2 its production side, and Section B.6.3 how it is used in policy simulations.

B.6.1 Households and demographics

For each skill type k, the earlier and later arrivals, $(k, \mathrm{F}^{\mathrm{old}})$ and $(k, \mathrm{F}^{\mathrm{new}})$, are separate groups on the household side: each has its own measure of households, value function, demographic flows, household size, and distribution of wealth, and everything in Sections B.2–B.4 applies to them unchanged. The $\mathrm{F}^{\mathrm{new}}$ groups have no households before the cutoff year and are filled over time by both channels of entry, new entrants at age J_B and immigrants. Until a group has residents at a given age, immigrants entering it are assigned the beginning-of-period distribution of the group or, if that is also empty, the distribution of new entrants in equation (20).

For survival probabilities (Section B.2.4) and the medical expenditures of additional adults (Section B.2.3), the nine-group model uses data pooled across groups with the same education level, as in the six-group model (Section B.1.4). In the nine-group model, each

foreign cohort simply joins the pool of its education level: the non-college pool contains $(\mathrm{NC}, \mathrm{US})$, $(\mathrm{NC}, \mathrm{F}^{\mathrm{old}})$, and $(\mathrm{NC}, \mathrm{F}^{\mathrm{new}})$, and the college-educated pool contains the remaining six groups. This matters most for the $\mathrm{F}^{\mathrm{new}}$ groups. In their first years they have few or no households, so their own distribution is not enough to compute these objects. With pooling, they take the same survival probabilities and the same medical expenditures of additional adults as the other groups with the same education level.

B.6.2 Production

In production, we assume that the two foreign cohorts of a given skill type and experience bracket are perfect substitutes, in contrast to the inputs combined at each level of the nest of Section B.5.1, which are imperfect substitutes. Their labor supplies, defined by equation (104), are therefore simply added together before entering the bottom level of the labor nest of Section B.5.1:

$$L_v^{k,\mathrm{F}} = L_v^{k,\mathrm{F}^{\mathrm{old}}} + L_v^{k,\mathrm{F}^{\mathrm{new}}}. \tag{113}$$

Although there are nine groups of households, production still distinguishes only U.S.-born and foreign labor within each skill type and experience bracket. The labor inputs of the nest are therefore the same as in the six-group model; the only difference is that the foreign input $L_v^{k,\mathrm{F}}$ now combines the labor of two groups of households instead of one. With this definition of $L_v^{k,\mathrm{F}}$, equations (105)–(108) and Figure 10 apply without change. Two implications follow from the perfect-substitutes assumption:

- the nine-group model adds no parameters to those of the six-group model (Section B.5.4), since no elasticity of substitution or efficiency parameter is needed to combine the two cohorts;
- the two foreign cohorts of a given skill type and experience bracket earn the same wage, $w_v^{k,\mathrm{F}}$, derived in Section B.5.3.

In addition, households in both foreign cohorts of the college-educated STEM groups

count toward the STEM population $N_{\mathrm{CS},t}$ of Section B.5.2.

B.6.3 Immigration policy

The nine-group model is motivated by policies that the six-group model cannot represent: policies that treat new immigrants differently from those already in the country. In the six-group model, any change in the rules for foreign households of a given skill type would apply to the whole existing foreign population. Splitting the foreign groups by arrival cohort makes it possible to change the rules for new arrivals only. This possibility is used only in policy simulations.[48]

Thus, in the baseline, all groups, including new arrivals, face the same tax, transfer, and health insurance rules of Section 1; in particular, foreign households choose whether to purchase insurance just as U.S.-born households do (Section 1.1.5.2).

In policy simulations, by contrast, an immigration policy can change both the number and composition of immigrants and the rules that apply to new arrivals. For example, households in the $\mathrm{F}^{\mathrm{new}}$ groups may be required to hold insurance, lose access to ACA subsidies and to the tax deduction for premiums, and receive no federal share of Medicaid spending, while all other households keep the baseline rules.

[48] More generally, the model allows several policy inputs to differ by group, including health insurance rules, Social Security benefit parameters, and some household tax parameters, such as the taxable share of labor income.

C Computational Implementation

This section describes how the model of Section 1 is solved numerically. The approach follows the computational algorithm of Nishiyama and Smetters (2014). The household state space is discretized, and the aggregate state is replaced by a perfect-foresight path of prices, policies and distributions. The household problem is solved by backward induction on its first-order and envelope conditions, and the distribution of households is tracked as a histogram on the grid. Equilibria are found by iterating on aggregate variables until they reproduce themselves. Sections 1.8–1.10 list the steps of these iterations, their damping weights and their convergence tolerances. This section describes the numerical methods used within each step and the software that runs them.

C.1 Software and Hardware

The model is written in Python, and its numerically intensive loops are compiled with Numba. The household problem runs on an NVIDIA graphics processing unit (GPU) through Numba's CUDA interface. The expectation and distribution steps run on the central processing unit (CPU) as parallel loops. Household value functions, decision rules and grids are stored in single precision.

We run the code on the University of Pennsylvania's PARCC supercomputer using NVIDIA DGX B200 nodes. Each iteration requires approximately five to ten minutes. Depending on the policy scenario, the single-group model converges in 15 to 30 iterations. Because we solve the household problem of each group sequentially, computation time scales with the number of groups: the 6-group model requires approximately six times as long as the single-group model, and the 9-group model approximately nine times as long.

C.2 Discretization of the State Space

The individual state $s = (j, a, b, z, h, d, i)$ of Section 1.1.1 is represented on the grid in Table 18. Age, ability, health status, the medical-expense shock and insurance status are discrete in the model. Wealth a and average historical earnings b are continuous and are approximated by the grids $A_G = \{a_1, \ldots, a_{N_a}\}$ and $B_G = \{b_1, \ldots, b_{N_b}\}$. The wealth nodes are an input in dollars that is converted to model units. The earnings-history nodes are

$$b_k = \vartheta_{\max} \left(\frac{k}{N_b} \right)^3, \qquad k = 1, \ldots, N_b, \tag{114}$$

where $\vartheta_{\max}$ is the OASDI taxable maximum of the initial steady-state year in model units, so that the nodes are concentrated at low earnings.

Table 18: Grid of the Household State Space

State variable	Symbol	Grid points
Age	j	80
Wealth	a	34
Average historical earnings	b	5
Labor ability	z	10
Health status	h	5
Medical-expense shock	d	3
Health insurance status	i	2
Grid points per year		4,080,000

Notes: Ages run from $J_B = 21$ to $J_D = 100$. Ability has nine regular states and a top-earner state (Section 1). The number of wealth nodes is set by the input wealth grid; the table shows the current baseline.

Two parts of the grid are never occupied. Retired households are pooled into the lowest ability state, and households of Medicare age are always insured. The code therefore skips the grid points of retired households with $z > z_1$ and of Medicare-age households with $i = 0$. In addition to the continuous choices c and l, the household makes the two binary choices $\iota \in \{0, 1\}$ and $i' \in \{0, 1\}$. Next-period insurance is fixed at $i' = 1$ for households who are Medicare-eligible next period and under policies that mandate coverage.

C.3 Prices and Policies along a Perfect-Foresight Path

Because there are no aggregate shocks, the household problem depends on the aggregate state only through the deterministic sequence $\Psi_t^{t+J_D-j}$ of prices, policies and distributions (Section 1.1.8). Following Nishiyama and Smetters (2014), the code does not carry the distribution as a state variable. Each model year instead holds its own guess of the aggregate variables that households take as given. These include the components of the return r_t in Equation (7), the wage w_t, the private insurance premium $p_{p,t}(j)$, inheritances $inh_t(j,z)$, the state income tax rate $\tau_{state,t}$ and the closure consumption tax rate. The household problem of year t is solved given that year's guess and the value functions of year $t+1$. In a steady state the guess is the same in every year, so the value functions of year $t+1$ are those of year t.

C.4 The Household Problem

C.4.1 Backward Induction

The household problem of each year is solved by backward induction over age, from J_D to J_B. At the terminal age J_D, the household does not survive to the next period and $V = u(c,l)$. At each age $j < J_D$, the code first computes, for every current state and every pair of discrete choices (i', ι), the expected continuation value at each node $(a_k, b_m) \in A_G \times B_G$,

$$\begin{aligned}\bar{V}_t(a_k, b_m; z, h, d, i', \iota) = \sum_{z'} \sum_{h'} \sum_{d'} \pi_z[z'|z]\, \pi_h[h'|j,h,d,\iota]\, \pi_d(d') \\ \times V\big((j+1, a_k, b_m, z', h', d', i'), \Psi_{t+1}^{t+J_D-j}\big).\end{aligned} \tag{115}$$

The expected marginal values $\bar{V}_{a,t}$ and $\bar{V}_{b,t}$ are computed in the same way from the marginal values $V_a = \partial V/\partial a$ and $V_b = \partial V/\partial b$ at age $j+1$. For households who retire at age $j+1$, π_z is replaced by a transition into the lowest ability state. These arrays are computed on the CPU and copied to the GPU. The continuous choices are then solved on the GPU with

one thread per grid point of age j, once for each pair of discrete choices, and each thread keeps the discrete choice with the highest value.

C.4.2 Interpolation

As in Nishiyama and Smetters (2014), $\bar{V}_t$, $\bar{V}_{a,t}$ and $\bar{V}_{b,t}$ are evaluated off the grid by bilinear interpolation in (a', b') over the four surrounding nodes. In the household problem, choices outside the grid are evaluated by linear extrapolation.

C.4.3 First-Order Conditions

Given (i', ι), the household chooses c and l. Let u_c and u_l be the marginal utilities of consumption and leisure, τ'_C the marginal tax rate on consumption and τ'_L the marginal tax rate on labor income. The residuals of the consumption Euler equation and of the labor-supply condition are

$$F_c(c,l) = \frac{1}{1+\tau'_C} - \frac{\beta\,\delta_t(j,h)\,\bar{V}_{a,t}(a',b')}{(1+\mu)\,u_c(c,l)}, \tag{116}$$

$$F_l(c,l) = 1 - \frac{u_c(c,l)}{u_l(c,l)}\,\frac{(1-\tau'_L)\,w_t\,e(j,h,z)}{1+\tau'_C} - \frac{\beta\,\delta_t(j,h)}{u_l(c,l)}\left(-\frac{\partial b'}{\partial l}\right)\bar{V}_{b,t}(a',b'), \tag{117}$$

where a' and b' follow from Equations (11) and (14). The last term of Equation (117) is the discounted marginal value of the higher average historical earnings that an additional unit of work generates. It is zero for households whose taxable earnings per adult exceed $\vartheta_{\max}$.

The borrowing constraint $a' \geq 0$ and the bounds on c and l turn these conditions into a nonlinear complementarity problem. Following Nishiyama and Smetters (2014), the code writes this problem as a system of two smooth equations using Fischer–Burmeister functions. The functions

$$\phi^-(x,y) = x + y - \sqrt{x^2+y^2}, \qquad \phi^+(x,y) = x + y + \sqrt{x^2+y^2}$$

are zero if and only if $\min\{x, y\} = 0$ and $\max\{x, y\} = 0$, respectively. The system is

$$\Phi_c(c, l) = \phi^-\big(\phi^+(F_c,\ \underline{c}^{num} - c),\ a'\big) = 0, \tag{118}$$

$$\Phi_l(c, l) = \phi^-\big(\phi^+(F_l,\ \underline{l}^{num} - l),\ \Omega_{a,t}(j) l_{\max} - l\big) = 0, \tag{119}$$

where $\underline{c}^{num} = \underline{l}^{num} = 0.001$ are numerical lower bounds. Retired households do not work: their leisure is set to $\Omega_{a,t}(j) l_{\max}$, and only Equation (118) is solved.

C.4.4 Solution of the First-Order Conditions

The code solves Equations (118)–(119) with Broyden's quasi-Newton method. The 2×2 Jacobian is estimated by finite differences at the starting point, and its inverse is updated with Broyden's "bad" update after each step. For retired households, the method reduces to a secant iteration on c. Steps are bounded in length, and iterates are projected onto the bounds on c and l. The Jacobian is re-estimated whenever an iterate is projected onto a bound and after every fifth step that does not reduce the residual. The iteration stops when the Euclidean norm of (Φ_c, Φ_l) falls below 10^{-4}, after 20 iterations, or after more than ten projected or non-improving steps, and it returns the best iterate found.

For $j < J_D$, the starting point is the solution most recently stored at the same grid point, which comes from age $j + 1$ or from a discrete choice already solved at age j. At J_D, the starting consumption is a. If Broyden's method does not reach the tolerance, the code evaluates the residual norm on a 20×15 grid of consumption and leisure, with consumption nodes concentrated near the lower bound. It then restarts Broyden's method from the best grid point with a smaller step bound. If the solution leaves end-of-period assets below 10^{-4}, consumption is lowered by bisection until $a' = 0$. If even near-zero consumption leaves $a' < 0$, the discrete choice is infeasible at that grid point and receives the value $-\infty$. At the solution, the value is

$$V(s, \Psi_t^{t+J_D-j}) = u(c, l) + \beta\big[\delta_t(j, h)\, \bar{V}_t(a', b') + \big(1 - \delta_t(j, h)\big)\zeta\big]. \tag{120}$$

C.4.5 Marginal Values

As in (Nishiyama and Smetters, 2014, equations 26–27), the marginal values of wealth and of average historical earnings at each grid point follow from the envelope conditions

$$V_a(s) = \frac{u_c(c,l)}{1+\tau'_C}\left(1 + r_t - \tau'_K\right), \tag{121}$$

$$V_b(s) = \frac{u_c(c,l)}{1+\tau'_C}\frac{\partial tr_{OASI,t}}{\partial b} + \beta\,\delta_t(j,h)\,\frac{\partial b'}{\partial b}\,\bar{V}_{b,t}(a',b'), \tag{122}$$

where τ'_K is the marginal tax on asset income per unit of wealth. The derivative $\partial b'/\partial b$ equals $(j-21)/(j-20)$ for workers and one for retirees. The marginal values at age j enter $\bar{V}_{a,t-1}$ and $\bar{V}_{b,t-1}$ at age $j-1$. In the current implementation, $\partial b'/\partial b$ omits the wage-indexing factor w_t/w_{t-1} of Equation (14), and r_t excludes capital gains r_t^C (Section 1.5.1).

C.5 The Distribution of Households

The distribution X_t is stored as a histogram that holds the mass of households at each grid point. Following Nishiyama and Smetters (2014), the mass at grid point s moves to the four nodes of $A_G \times B_G$ that surround the household's choices $(a'(s), b'(s))$, with bilinear weights

$$\omega_{k,m}(s) = \omega^a_k\big(a'(s)\big)\,\omega^b_m\big(b'(s)\big), \tag{123}$$

where ω^a_k and ω^b_m are the linear interpolation weights on a_k and b_m. Unlike in the household problem, there is no extrapolation: a choice outside the grid is assigned to the nearest boundary node. The mass is multiplied by $\pi_z[z'|z]$, by $\pi_h[h'|j,h,d,\iota(s)]$, by the i.i.d. shock density $\pi_d(d')$ and by the survival probability net of emigration, $\tilde{\delta}_t(j,h)$ in Equation (23), with $i' = i'(s)$ as in Equation (26). With multiple demographic groups, $\tilde{\delta}_t(j,h)$ is also net of switches to other groups (Section B). Immigrants, households switching between groups and the scaling vector π^s_{t+1} are applied afterwards. Households entering at age J_B are placed at the lowest nodes of A_G and B_G, which represent $a = 0$ and $b = 0$, and their

insurance status is chosen as in Section 1.2.1.

In a steady state, the stationary distribution implied by the household decision rules is obtained in one forward pass over age. Ages are processed in order from J_B, and the mass at age $j+1$ is computed from the mass just computed at age j. On a transition path, the distribution of year $t+1$ depends only on that of year t, so all ages are updated in parallel.

C.6 Steady States

A steady state is a fixed point in the aggregate variables that households and firms take as given. Following Nishiyama and Smetters (2014), the code finds it by Gauss–Jacobi iteration. Each iteration performs the following steps:

(i) In the baseline, recalibrate the survival probabilities with Equation (78).

(ii) Solve the household problem in one backward pass over age (Section C.4).

(iii) Compute the stationary distribution in one forward pass over age (Section C.5) and aggregate household decisions.

(iv) Compute factor prices and dividends from the firm problem, without damping.

(v) Update the government budget, including the state income tax rate, magic money and the closure tax rate.

(vi) Check convergence and, if the check fails, damp the new guess of the feedback variables.

Convergence is measured for each aggregate x by the relative change

$$\varepsilon_x = \frac{x^{new} - x^{ref}}{\max\left\{|x^{ref}|, \underline{x}\right\}}, \tag{124}$$

where x^{new} is the value the iteration implies and $\underline{x}$ is a variable-specific floor. For a damped variable, x^{ref} is the guess that entered the iteration; for any other variable, it is the value of

the previous iteration. Section 1.8 gives the damped variables, the damping weights, the tolerances and the iteration limits. The initial steady state starts from the solution saved by the calibration (Section 2).

C.7 Transition Paths

As in Nishiyama and Smetters (2014), a transition path runs from the initial steady state in year T_0 to a final steady state in year T_f. In the current baseline, $T_0 = 2024$, $T_c = 2061$ and $T_f = 2071$. Year T_0 is a copy of the initial steady state and is not re-solved. Each iteration of the outer loop performs the following steps:

(a) Solve the final steady state as in Section C.6, given the beginning-of-year debt and foreign holdings of year $T_f - 1$.

(b) Solve the household problem backward in calendar time from $T_f - 1$ to $T_0 + 1$. Each year uses the value and marginal-value functions of the following year, so year $T_f - 1$ uses those of the final steady state.

(c) Update the distribution forward in calendar time from T_0 and aggregate household decisions in each year.

(d) Compute factor prices and dividends in each year.

(e) Update the government budget forward from $T_0 + 1$, carrying debt, foreign holdings, the maturity structure and coupons to the next year, and update the average wage index from the path of real wages.

(f) Check convergence in every year and, if the check fails, damp the new guess of the path.

All years are updated from the same guess of the path, so the update is Gauss–Jacobi across years as well as across variables. In the baseline, the survival probabilities are recalibrated in every iteration (Section 2.6.4). Section 1.9 gives the initial guess of the baseline

path, the damping weights and the tolerances. A policy path starts from the baseline path. The loop stops after at most 30 iterations. The code reports the iteration with the smallest maximum residual and saves the last iterate. The static policy simulation of Section 4.1 does not run this loop; it aggregates, updates production and updates the government budget once, using the baseline household decision rules and distribution.

C.8 Implementation Notes

The GPU kernels are compiled once per run and are shared by all years and demographic groups. Year- and group-specific inputs reach the kernels as arguments at launch. With multiple demographic groups (Section B), the household problem of each group is solved separately with the same kernels. In the current baseline, one year of the household problem covers about 4.1 million grid points, each solved for up to four pairs of discrete choices. One iteration of the transition path solves the final steady state and the 46 years from $T_0 + 1$ to $T_f - 1$.

References for Appendix

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D Index of Variables and Parameters

This index lists the variables and parameters of the documentation by theme and, within each theme, alphabetically, with Latin letters before Greek letters. The page numbers link to the pages that define or use each symbol. A symbol with more than one meaning is listed once for each meaning.

Symbol	Description	Pages
Time, ages and indices		
b	Business type, corporate or pass-through	25
j	Age of the household head	7, 8
j	Production sector	24, 87
J	Set of ages	7, 8
J_B	Age at which households enter the model	7, 18, 53
J_D	Maximum age	7, 53
n	Number of production sectors	24, 87
p_t, P	Vector of prices in year t; set of price vectors	9, 43
p_t^T	Sequence of price vectors from t to T	9
t	Calendar year (model period)	7
T	Year after which the economy is in its terminal steady state	44
T_0	Initial year of the transition path	43, 44, 45, 100, 153
T_c	Closure year, the last year for which government policies are specified	40, 45, 46, 47, 100, 153
T_f	Year in which the final steady state is reached	45, 46, 47, 100, 153
ψ_t	Government policy in year t	8, 43, 45, 47, 100, 105, 106, 107, 108, 111
ψ_t^T	Sequence of government policies from t to T	9, 36
Ψ_t^T	Sequence of prices, policies and distributions from t to T	9, 111, 112, 148
Demographics and population		
$\mathbb{1}_i(z, h)$	Indicator that an entrant with ability z and health h is insured	19
$de_t(j)$	Deaths at age j projected by Microsim	22, 53, 101
$em_t^{rate}(j)$	Emigration rate by age	21

(continued)

Symbol	Description	Pages
$em_t(j)$	Emigrants of age j	18, 21, 22, 53, 100, 101
$EV_{0,t}$, $EV_{1,t}$	Expected value of an entrant without and with insurance	19
$im_t(j)$	Immigrants of age j	18, 20, 21, 22, 53, 100, 101
$J_{Mcare,t}$	Medicare eligibility age	8, 11, 53
$J_{R,t}$	Retirement age	8, 10, 16, 32, 53
nb_t	Households entering the model through birth	18
$\hat{x}_{t+1}^{forecast}(j)$	Population of age j before rescaling	22
$\hat{x}_t^{microsim}(j)$	Population of age j projected by Microsim	21, 22, 53, 100, 101, 102
$\tilde{X}_t$	Measure of residents after survival and emigration	20
$\hat{x}_t(j)$	Model population of age j	69
$\tilde{x}_t(j,h)$	Population density by age and health status	69
$x_t(s)$, X_t	Density and measure of households over states	18, 23, 43
$\delta_{j,h}^{MEPS}$	Survival probability by age and health status estimated from MEPS	67, 69, 132
$\delta_{j,t}^{microsim}$	Survival probability by age projected by Microsim	68, 69, 100, 102
$\delta_t(j,h)$	Survival probability by age and health status	8, 14, 15, 21, 36, 69, 119, 120, 121, 149, 150, 151
$\tilde{\delta}_t(j,h)$	Survival probability net of emigration	21, 23, 151
π_h^0, π_z^0	Initial distributions of health status and ability	10, 18, 19, 127
π_t^{immi}, Π_t^{immi}	Density and measure of immigrants over states	19, 20, 21, 23
$\pi_{NB,t}$, $\bar{\pi}_{NB}$	Density of entrants at age J_B; the same density integrated over insurance status	19, 20
$\pi_{t+1}^s(j)$	Scaling vector that matches the model population to Microsim	22, 23, 43, 54, 151
$\varphi_{j,t}$	Exponent that adjusts MEPS death rates to Microsim mortality	69
$\Omega_{a,t}(j)$, $\Omega_{c,t}(j)$	Number of adults and of children in an age-j household	8, 9, 10, 11, 12, 13, 16, 17, 23, 32, 43, 53, 63, 89, 90, 91, 129, 130, 150
$\omega_{j,h,t}$	Share of age-j households in health state h	69

(continued)

Symbol	Description	Pages
Household states and decisions		
$a \in A$	Beginning-of-period wealth; wealth domain $[a_{\min}, a_{\max}]$	7, 8
a'	Wealth carried into the next period	15, 16, 18
$b \in B$	Average historical earnings used for OASI benefits; domain $[0, b_{\max}]$	7, 8, 16
c	Consumption	9, 15
$d \in D$	Medical-needs (expenditure) shock	8, 10, 11, 62, 63, 66
$h \in H$	Health status; $h_{\max}$ is the number of health states	8, 72, 73
$i \in I$	Health insurance status	8, 12
l	Leisure	9, 10
$s \in S$	Household state; state space	8, 111, 112
V	Household value function	15, 19
$z \in Z$	Persistent labor productivity (ability)	7, 8, 10, 57, 58, 59
Γ_h	Household decision rules	15, 18, 23, 43, 105, 111, 119, 120
ι	Decision to receive medical treatment	8, 11, 15, 67, 71
Preferences		
$l_{\max}$	Maximum leisure hours per adult	9, 10, 16, 43, 52, 55, 56, 129, 130, 138, 150
$u(c, l)$	Period utility function	9, 15, 54, 119, 128, 148, 150
α	Weight of consumption in utility	9, 50, 52, 54, 55, 56
β	Discount factor	15, 52, 56
$\tilde{\beta}$	Discount factor adjusted for productivity growth	15, 56, 119, 120, 121
γ	Coefficient of relative risk aversion	9, 50, 52, 54, 55, 56
ζ	Value of death	14, 15, 17, 52, 61, 65, 66, 73, 74, 119, 120, 121, 122, 123, 124, 128, 150
Labor productivity and earnings		
$e_{\min}, e_{\max}$	Bounds on labor productivity	10
$e(j, h, z)$	Labor productivity by age, health status and ability	10, 57, 127, 129, 138, 149

(continued)

Symbol	Description	Pages
$\bar{e}(j,h)$	Average working ability by age and health status	57, 58
w_t	Wage per efficiency unit of labor	10, 32
y_t^G	Gross labor income	10, 13, 32
y_t^P	Paid labor income, net of the employer's share of the ESI premium	12, 13, 16, 32, 91, 92
y_t^T	Taxable labor income	12, 13, 16, 17, 36, 37, 78, 81, 86, 102
ϵ_z	Innovation to ability	58
π_z	Transition probabilities of ability	10, 23, 127, 136, 148, 151
ρ	Persistence of ability	58, 59
σ_z	Standard deviation of the innovation to ability	58, 59
Medical spending and health		
m^C	Medical expenditures of each child	10, 11, 63, 130
m^H	Medical expenditures of the household head	10, 11, 63, 130, 131
m^S	Medical expenditures of each additional adult	10, 11, 63
$\tilde{m}_t$	Medical expenditures before health-care price growth	10, 11
$m_{T_0}(j,h,d)$	Medical expenditures in the initial year	45, 72
$m_t(j,h,d,i;X)$	Household medical expenditures	10, 11, 23, 37, 43
$oop_t(m,i)$	Out-of-pocket medical spending	10, 11, 16, 17, 23, 36, 37, 102
R_5	Ratio of average medical spending of the uninsured to the privately insured in health state 5	66
S_U, S_P	Sets of uninsured and privately insured households in the spending-ratio target	66, 122, 123
$\gamma^{ht}(h,h')$	Direction of health transitions without treatment	50, 52, 72, 73
$\gamma^{oop}(m,i)$	Out-of-pocket share of medical spending	10, 11, 66
$\bar{\gamma}_t^{oop}$	Household out-of-pocket share, averaged over members by expenditure	11
$\delta^{ht}(h)$	Intensity of health deterioration without treatment	50, 51, 52, 72, 73, 123
κ_i	Administrative cost share of insurance type i	23, 24, 43, 137
$\nu_t^m(i)$	Health-care price growth by insurance type	10, 11, 12, 67

(continued)

Symbol	Description	Pages
π_d	Distribution of the medical-needs shock	10, 18, 19, 23, 136, 148, 151
$\pi_h[h'\|j,h,d,\iota]$	Health transition probabilities	8, 11, 23, 67, 71, 72, 73, 131, 136, 148, 151
π_h^{unins}	Health transition probabilities of the uninsured	72
ω^{hp}	Weights that convert transitions with treatment into transitions without	71, 72, 73
Health insurance		
aca_{cutoff}	Income limit for ACA marketplace eligibility	52, 82
$\overline{D}^{ESI}$	Cap on the exclusion of ESI premiums from taxable labor income	13
e_t^{ESI}	Indicator that a household enrolls in ESI	12, 13
$Med_{Mcare,t}$, $Med_{Mcaid,t}$	Medicare and Medicaid policy parameters	8
o_t^{ESI}	Indicator that a household is offered ESI	12, 13, 16, 32
$p_{Mcare,t}$	Medicare premiums paid by enrollees	37
$p_{p,t}(j)$	Private insurance premium per person	12, 13, 16, 23, 32, 43, 81, 128, 148
p_t^p	Private health insurance premium, as an equilibrium price	43, 45, 46, 48, 49
RCP	Required contribution percentage for ACA premium subsidies	81
$\underline{y}^{ESI}$	Labor-income threshold for an ESI offer	12, 52, 79, 81
η^{ESI}	Employer share of the ESI premium	12, 13, 16, 32, 81
$\nu_{i,t}$	Premium growth rate by insurance type	45, 47, 100
$\pi_{Mcare,t}(y,j)$	Medicare premium by income and age	12, 16
$\pi_{ACA,t}^{PremSub}$	ACA premium subsidy	8, 13, 16, 37, 81
$\Pi_t(j)$	Measure of privately insured households of age j	23
$\pi_t(s,l)$	Health insurance premium paid by the household	16
ς	Ratio of the average marketplace premium to the benchmark premium	81, 82
ω_j^{HI}	Age weights in the private insurance premium	23, 52, 79, 81, 82

(continued)

Symbol	Description	Pages
Assets, returns and bequests		
$\tilde{a}'$	Bequest net of transaction costs	14
$a'_{\min}(s)$	Borrowing limit	16
i_t^G	Nominal taxable return on government bonds	16, 42, 43
$inh_t(j,z)$	Inheritance received by age and ability	15, 16, 148
Q_t	Pool of bequests distributed as inheritances	14, 15, 61, 132
r_t^{corp}, r_t^{pass}	Dividends on corporate and pass-through capital	14, 16, 41, 42, 43
r_t^C	Capital gains on household wealth	14, 16, 41, 42, 43, 151
r_t^G	Interest on one-period government debt	14, 41, 42, 43
r_t^K	Return on physical capital	43
r_t	Return on household wealth	14, 16, 31, 41, 43, 46, 49, 148, 151
$\tilde{r}_t$	Taxable return on household wealth	16, 17, 102
$\Xi(a')$	Transaction costs on bequests	14, 36, 61, 103
$\omega^q(j,z)$	Relative size of inheritances by age and ability	15, 61, 132, 133
Household taxes and transfers		
$BL_t(j)$, $\bar{BL}_t$, $\hat{BL}_t$	SNAP benefit limit by household size; its intercept and slope	91
$\underline{c}$	Consumption floor	16, 17, 56
coh_t	Cash on hand before medical spending	16, 17
$\widehat{coh}_t$	Resources after out-of-pocket medical spending	16, 17
GIL	SNAP gross income limit	90, 91
NIL	SNAP net income limit	91
$\overline{oop}_t$	Cap on the income tax deduction of out-of-pocket medical spending	17, 102
$PIA_{z,j,t}^{OASDI_calc}$, $AWI_{t(j=60)}^{OASDI_calc}$	PIA bend point and average wage index from the OASDI calculator	90
$PIA_{z,j,t}^r$	Replacement rate in PIA bracket z	89, 102
$PIA_{z,j,t}$	Bend point of primary insurance amount (PIA) bracket z	89, 90, 102
p_{t-j}^t	Prices from year $t-j$ to t, which determine OASI benefits	16, 36, 37, 89, 90, 102
$rc_t(j)$	Refundable tax credits	16, 17, 36, 96, 102

(continued)

Symbol	Description	Pages
SC_t, SC_t^{MAX}	Shelter costs; cap on the SNAP shelter deduction	91
$SD_{snap,t}$	SNAP shelter deduction	91
SN_t	SNAP benefit	8, 16, 17, 37, 91, 103
$\tilde{SN}_t$	Standard SNAP benefit before the top-up	16, 17, 91
SSI_t	SSI benefit	8, 16, 37, 92, 103
$tr_{OASI,t}$	OASI benefit	8, 10, 16, 17, 36, 37, 89, 102, 151
$T_t(s,c,l)$	Taxes net of transfers paid by the household	16
$w_{t(j=60)}$	Average real wage in the year the household turns 60	89, 90
y_t^{NI}	SNAP net income	91
y^{secA}	SNAP Section A income	91
Z	Number of PIA brackets	89
η_0^y, η_1^y	Offset and share that map taxable labor income into the payroll tax base	17, 36, 38, 86
$\vartheta_{\max}$	OASDI taxable maximum	16, 17, 86, 147, 149
ϑ_{HI}	Income threshold for the HI surtax	86, 87
$\tau_{C,t}$	Consumption tax rate	8, 9, 16, 36, 37, 49
$\tau_{E,t}$	Estate tax function	8, 9, 14, 36, 61, 102
$\tau_{HI,t}$, τ_{HI2}	Hospital Insurance payroll tax rate; HI surtax rate	36, 37, 86
$\tau_{I,t}$	Federal income tax function	8, 16, 17, 36, 102
$\tau_{O,t}$	OASDI payroll tax rate	36, 37, 86
$\tau_{P,t}$	Payroll tax function	8, 9, 16, 17, 36, 86, 102
$\tau_{state,t}$	State income tax function	8, 9, 16, 17, 36, 38, 45, 48, 49, 97, 148
$\tau_{W,t}$	Wealth tax rate	8, 9, 16, 17
ψ_t^C	Taxable share of consumption	16, 36
ψ_t^W	Taxable share of assets	16, 17
Production		
$A_{j,t}$	Total factor productivity of sector j	25, 34, 89, 141
$C(I_t, K_t)$	Capital adjustment cost	27, 28, 29, 31
$F(K,L)$, F^K	Production function; marginal product of capital	28, 31, 33
$I_{b,j,t}$, I_t	Investment	26, 27, 28, 29, 31

(continued)

Symbol	Description	Pages
$K_{b,j,t}$	Capital by business type and sector	25, 26, 27, 28, 31, 33, 43, 44, 46, 47, 48
$K_{j,t}$	Capital of sector j	25, 30, 34
$L_{b,j,t}$	Labor by business type and sector	25, 27, 28, 31
$l_{j,t}$	Share of aggregate labor employed in sector j	34
$L_{j,t}$	Labor of sector j	25, 32, 34
$p_{j,t}$	Price of the sector-j good	24, 27, 28, 31, 34, 43, 46, 49
q_t^{exist}, q_t^{new}	Price of existing and of new capital	28, 30
q_t	Price of capital	28, 30, 31
$R_{b,t}$	Mutual fund earnings from business type b	28, 41
$V_{b,j,t}$	Firm value	31, 33
$\bar{V}_{b,j,t}$	Exogenous payments that do not affect the firm's optimization	31
$Y_{b,j,t}$	Output by business type and sector	25, 27, 28
$Y_{j,t}$	Output of sector j	24, 25, 34
Y_t	Final output	24, 32, 46, 49, 56
$\alpha_{j,t}^f$	Capital share in sector j	25, 32, 34, 35
$\Gamma_{b,j}^f$	Firm decision rules	32, 43, 105
$\delta_{k,j}$	Depreciation rate of capital in sector j	26, 28, 31, 33, 34, 88
$\zeta_{b,j,t}^{income}$	Share of sector capital and labor in business type b	25, 30, 35
ζ_j	Weight of sector j in final output	24, 32, 34, 35, 87
η	Capital adjustment cost parameter	31, 89
μ	Growth rate of labor-augmenting productivity	15, 16, 17, 53, 56, 119, 149
$\nu(\cdot)$, ν_1, ν_2	Cost of leverage and its parameters	27, 28, 31, 33, 34, 88
$\pi_{b,j,t}$	Dividends per unit of capital	28
$\Phi_{b,j,t}^R$	Tax-adjusted user cost of capital	33, 34, 35
$\Phi_{b,j,t}^W$	Tax wedge in the labor first-order condition	32, 34
Business taxation		
$B_{b,j,t}$	Business debt	27, 28, 31, 33
$pgdp_t$	GDP price index	26, 29
$T_{b,j,t}$	Business tax liability	27, 28, 36

(continued)

Symbol	Description	Pages
T_d	Length of the depreciation schedule	8, 26, 29, 31, 32, 36, 43, 44, 46, 47, 88
$\Gamma_{b,j,t}$	Implicit investment subsidy	29, 31, 33, 34
$\zeta^{cred}_{b,j,t}$	Output tax credit share	8, 9, 27, 28, 31, 32, 33, 34, 88, 104
$\zeta^{ded}_{b,j,t}$	Share of other deductions	8, 9, 27, 28, 31, 32, 33, 34, 87, 88, 104
$\zeta^{itc}_{b,j,t}$	Investment tax credit rate	8, 9, 27, 28, 29, 32, 88
$\zeta^{other}_{b,j,t}$	Other deductions in the dividend equation	28, 88
$\Pi^{taxable}_{b,j,t}$	Business taxable income	27
$\rho_{b,j,t}$	Interest rate on business debt	27, 28, 31, 33, 34, 88
$\rho(K_{b,j,t})$	Total cost of borrowing	27
$\tilde{\tau}_{b,j,t}$	Tax rate at which deductions are taken	29
$\tau_{corp,t}$	Business tax function	36
$\tau^{statutory}_{b,j,t}$	Statutory business tax rate	8, 9, 27, 28, 29, 31, 32, 33, 34, 88, 97, 104
$\tau^{top}_{pit,t}$	Top individual income tax rate	29
$\phi_{b,j,t,i}$	Share of investment deductible i years after purchase	8, 9, 26, 29, 88, 104
$\phi^{exp}_{b,j,t,i}$	Expensing deductions for past investment	26, 27, 28, 31
$\phi^{int}_{b,j,t}$	Deductible share of interest	8, 9, 27, 28, 31, 33, 34, 88, 104
$\phi^{npv}_{b,j,t}$	Present value of deductions per unit of new capital	29
Government budget and debt		
$B(IM_k)$, $\omega(IM_k)$, $g_t(IM_k)$	Maturity bucket of issue maturity IM_k; its target share; its gap	39
$C_{G,t}$	Exogenous government outlays	8, 9, 37, 103
D^G_t	Debt held by the public	38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49
$d_t(m)$	Outstanding debt by maturity	39, 40, 98
ey_t	Effective coupon rate by maturity	38, 40, 43, 98, 99
i^D_t	Nominal effective interest rate on government debt	29, 40, 42, 43, 98
IM, IM_k	Maturities at which new debt is issued	38, 39

(continued)

Symbol	Description	Pages
$M_{ACA,t}$, $M_{Mcare,t}$, $M_{Mcaid,t}$	Outlays for ACA subsidies, Medicare and Medicaid	36, 37, 38
mm_t	Transfer that balances the budget when debt is set exogenously	37, 38, 43, 44
$nd_t(m)$	New debt issued by maturity	39, 40
NI_t^G	Net interest on government debt	38, 39, 40
N_t	Face value of newly issued debt	39, 40
pd_t	Primary deficit	37, 39
r_t^D	Real effective interest rate on government debt	40, 41, 43
$T_{C,t}$	Consumption tax revenues	36, 37
$T_{corp,t}$	Business tax revenues	36, 37
$T_{E,t}$	Estate tax revenues	36, 37
$T_{exog,t}$	Exogenous revenues	37, 38, 103
$T_{I,t}$	Income tax revenues	36, 37
T_m, $\mathcal{T}_m$	Longest maturity of government debt; set of maturities	38, 39, 100
$T_{P,t}$	Payroll tax revenues	36, 37
$TREAS$	Set of marketable Treasury bills, notes and bonds	98, 99
$TR_{OASI,t}$	OASI outlays	36, 37
$TR_{SNAP,t}$, $TR_{SSI,t}$	SNAP and SSI outlays	37, 38
$T_{S,t}$	State tax revenues	36, 38
W_t^F	Foreign holdings of government debt	40, 41, 42, 43, 44, 45, 46, 47, 48, 49
yc_t	Yield curve	38, 40, 43, 100
Λ	A Treasury security; mat, out and int give its maturity, outstanding value and coupon rate	98, 99
π_t^{CPI}	CPI-U inflation	39, 40
ϱ_t^M, ϱ_t^{SN}	Federal shares of Medicaid and SNAP spending	37, 38
ϕ_t^D	Foreign share of net new debt issues	40, 98
Aggregation and equilibrium		
A_{t+1}	Aggregate household wealth	41, 43, 137
K_t	Aggregate capital	27, 28, 29, 31, 41, 42, 43, 56
L_t	Aggregate labor in efficiency units	43, 138
M_t	Aggregate medical expenditures	43, 137

(continued)

Symbol	Description	Pages
Δq_t	Capital gains on existing capital	41
$\pi_{j,t}$	Population scaling factors, equal to the scaling vector $\pi_t^s(j)$	43, 44, 47
Calibration and solution algorithm		
BT	Mapping that computes a baseline transition path	47
$\bar{h}^*$	Target for average hours worked	52
ISS	Mapping that computes the initial steady state	50, 51
k	Fixed gain in a calibration update	52
m	Model value of a calibration moment	52
$\bar{m}$	Smoothed model value of a calibration moment	52
$\mathcal{M}$	Target value of a calibration moment	52
$\mathcal{M}^I$	Targeted values of the internally calibrated moments	50, 51
N^I	Number of internally calibrated moments	47, 50, 51
S_n	Fit of calibration iteration n	51
$x_{j,t}^{est}$	Target population by age	45
ϵ_i	Tolerance for calibration moment i	50, 51
θ, θ_t	Vector of model parameters	44, 45, 46, 47, 50, 51
θ^I	Internally calibrated parameters	50
θ_n	Guess of the internally calibrated parameters in iteration n	50, 51
λ	Gain in a calibration update; shrinks when the gap changes sign	52
$\hat{\tau}_{C,t}$	Consumption tax rate that closes the budget	47, 48
$\bar{\Omega}$	Average number of adults in working households	52, 55
Policy simulation and welfare		
adj_t	Yearly adjustment applied to a policy input	108, 109
AEV	Aggregate equivalent variation	111
$ev(s,\cdot)$	One-time wealth transfer that makes a household indifferent to the policy	111
p_t'	Vector of prices under the policy	111, 112
$\hat{s}$	Household state with the transfer added to wealth	111

(continued)

Symbol	Description	Pages
$\tilde{S}$	Subset of states over which welfare is aggregated	111, 112
S_Γ	States in which the endogenous outcomes match	111
T_e	Year in which the policy is announced	112
$\hat{x}'$, $\delta'^{microsim}$, em'_t, im'_t	Demographic inputs under the policy	105
X, X'	Distribution of households in the baseline and under the policy	105, 110, 111, 112
Y_{T_0}, Y'_{T_0}	Initial-year output in the baseline and under the policy	43, 45, 105, 109
Γ	Set of endogenous outcomes held fixed in a welfare measure	111
Γ'_h, Γ'^f	Household and firm decision rules under the policy	109
ψ'_t	Alternative policy schedule of a policy simulation	47, 105, 106, 108, 109, 111
ψ''_t	Adjusted policy schedule	107, 108, 109
Ψ'^T_t	Sequence of prices, policies and distributions under the policy	111, 112
Value of death (Appendix A)		
$A(s)$	Base of the proportional value of death	121
D^B	Discounted, survival-weighted sum of the death terms along the baseline path	124
R^*_5	Target ratio of uninsured to privately insured spending in health state 5	123
$R^{(n)}_5$, $\bar{R}^{(n)}_5$	Model spending ratio in iteration n; its smoothed value	123
V^B, V^P	Baseline and policy value	124
$\bar{V}(s)$	Expected continuation value	120, 121, 122, 124
$x^{(n)}$	Clipped update step in iteration n	123
Δ	Change in the survival probability	120
ζ_0, ζ_1, $v(a')$	Joy-of-giving alternative: intercept, weight and utility of the estate	122
$\zeta^{(n)}$	Value of death in iteration n	123
λ	Consumption-equivalent variation	124

(continued)

Symbol	Description	Pages
Multiple demographic groups (Appendix B)		
$\bar{A}_{j,t}$	Exogenous component of total factor productivity	141
de_t^g, em_t^g, im_t^g	Deaths, emigrants and immigrants of group g	133, 134, 136, 137
$em_t^{rate,g}(j)$	Emigration rate of group g	134, 135
F, F^{old}, F^{new}	Foreign-born households; foreign cohorts that arrived before and after a cutoff year	126, 127, 133, 140, 142, 143, 144, 145
g	Demographic group	126, 127
$\mathcal{G}$, $\mathcal{G}^6$, $\mathcal{G}^9$	Set of groups; six-group and nine-group sets	125, 126, 137, 142
k	Skill type	126, 140
L_C, L_k, $L_{k,v}$	Labor aggregates of the CES nest	139, 140, 141, 142
$L_{v,t}^g$	Labor supplied by group g in experience bracket v	138, 141
$L_v^{k,US}$, $L_v^{k,F}$	Labor of U.S.-born and foreign workers of skill type k in bracket v	140, 144
m^g	Medical expenditures of a group-g household	130, 131, 134, 136, 137
$m_t^{S,\mathcal{P}(g)}(j)$	Medical expenditures of each additional adult in pool $\mathcal{P}(g)$	130, 131
NC, CNS, CS	Skill types: non-college, college non-STEM, college STEM	126, 127, 139, 140, 141, 142, 143, 144, 145
$N_{CS,t}$	College-educated STEM population	141, 145
$\mathcal{P}(g)$	Education-level pool of group g	127, 130, 131, 132
Q_t^g, $inh_t^g(j,z)$	Inheritance pool and inheritance of group g	132, 133
$tr_t^{g'\to g}(j)$	Households of age j moving from group g' to group g	134, 135
$tr_t^{in,g}$, $tr_t^{out,g}$	Total moves into and out of group g	134, 135, 136, 137
$tr_t^{out,rate,g}$	Rate at which households leave group g	134, 135
US	U.S.-born households	126, 127, 140, 141, 142, 143, 144
v, $v(j)$	Experience bracket; bracket of age j	128
V^g	Value function of group g	127, 128, 133
w_v^g	Wage of group g in experience bracket v	129, 138, 141, 142, 144
$\hat{x}_{t+1}^{forecast,g}$	Population of group g before rescaling	136
X_t^g	Measure of group-g households	127, 132, 133, 136, 137, 138

(continued)

Symbol	Description	Pages
$\tilde{X}_t^g$	Measure of group-g residents after survival and emigration	134
x_{t+1}^g	Density of group-g households	136
$\hat{x}_t^{microsim,g}$	Microsim population of group g	134, 136
$y_t^{G,g}$	Gross labor income of group g	129
Γ_h^g	Decision rules of group g	127, 128, 136
$\delta_t^g(j,h)$	Survival probability of group g	128, 131, 132, 135
$\tilde{\delta}_t^g(j,h)$	Survival probability of group g net of emigration and moves	135, 136, 137
$\delta_{j,t}^{microsim,\mathcal{P}(g)}$	Microsim survival probability of pool $\mathcal{P}(g)$	132
$\pi_t^g(\cdot\|j)$	Distribution of age-j households of group g over states	135
$\pi_t^{immi,g}$	Distribution of immigrants into group g	134, 136, 137
$\pi_{t+1}^{s,g}(j)$	Scaling vector of group g	136, 137
$\pi_t^{sw,g}$	Distribution of switchers arriving in group g	135, 136, 137
$\varpi_C, \varpi_{NC}, \varpi_{CS}, \varpi_{CNS}$	Efficiency parameters of the education and occupation nests	139, 140, 141, 142, 143
$\varpi_{k,v}, \varpi_{k,US}, \varpi_{k,F}$	Efficiency parameters of the experience and nativity nests	140, 143
$\sigma_{COL}, \sigma_{STEM}$	Elasticities of substitution between college and non-college, and STEM and non-STEM workers	139, 140, 141, 142, 143
$\sigma_{EXP,k}, \sigma_{NAT,k}$	Elasticities of substitution across experience brackets and between U.S.-born and foreign workers	140, 141, 142, 143
$\varphi_{j,t}^g$	Survival exponent of group g	132
χ	Elasticity of total factor productivity with respect to the STEM population	141, 143
$\Omega_{a,t}^g(j), \Omega_{c,t}^g(j)$	Number of adults and children in a group-g household	127, 129, 130, 138
$\omega^{\mathcal{P}(g)}$	Health and expenditure shares in pool $\mathcal{P}(g)$	131, 132
Computational implementation (Appendix C)		
A_G, B_G	Grids for wealth and average historical earnings	147, 148, 151
a_k, b_m	Nodes of the wealth and earnings grids	148, 151
b_k	Earnings-history node	147
$\underline{c}^{num}, \underline{l}^{num}$	Numerical lower bounds on consumption and leisure	150

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Symbol	Description	Pages
F_c, F_l	Residuals of the consumption and labor first-order conditions	149, 150
N_a, N_b	Numbers of wealth and earnings grid points	147
u_c, u_l	Marginal utilities of consumption and leisure	149, 151
V_a, V_b	Marginal values of wealth and average historical earnings	148, 151
$\bar{V}_t$, $\bar{V}_{a,t}$, $\bar{V}_{b,t}$	Expected continuation value and expected marginal values	148, 149, 150, 151
x^{new}, x^{ref}, $\underline{x}$	Iteration value, reference value and floor of aggregate x	152
ε_x	Relative change of aggregate x between iterations	152
τ'_C, τ'_L	Marginal tax rates on consumption and labor income	149, 151
ϕ^-, ϕ^+	Fischer–Burmeister functions	149, 150
Φ_c, Φ_l	Complementarity system for consumption and leisure	150
$\omega_{k,m}(s)$, ω^a_k, ω^b_m	Bilinear weights of the distribution update	151