Optimal Progressive Income Taxation in a Bewley-Grossman Framework*

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Abstract

We study the optimal progressivity of income taxation in a Bewley-Grossman model of health capital accumulation where individuals are exposed to earnings and health risks over the lifecycle. We impose the U.S. tax and transfer system and calibrate the model to match U.S. data. We then optimize the progressivity of the income tax code. The optimal income tax system is more progressive than current U.S. income taxes with zero taxes at the lower end of the income distribution and a marginal tax rate of over 50 percent for income earners above US$200,000. The Suits index—a Gini coefficient for the income tax contribution by income—is around 0.53 and much higher than 0.17 in the U.S. benchmark tax system. Welfare gains from switching to the optimal tax system amount to over 5 percent of compensating consumption. Moreover, we find that the structure of the health insurance system affects the degree of optimal progressivity of the income tax system. The introduction of Affordable Care Act in 2010—a program that redistributes wealth from high income and healthy types, to low income and sicker types—reduces the optimal progressivity level of the income tax system. Finally, we demonstrate that the optimal tax system is sensitive to the parametric specification of the income tax function and the transfer policy.

JEL: E62, H24, I13, D52

Keywords: Health risk, Inequality, Tax progressivity, Suits index, Social insurance, Optimal tax, General equilibrium.

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1 Introduction

The social insurance literature views income risk as an important source of income, wealth and consumption heterogeneity (e.g., Heathcote, Storesletten and Violante (2008) and Kaplan (2012)). More recently Capatina (2015) identifies health risk as another important source of heterogeneity with large implications for the household consumption-savings decision and macroeconomic aggregates. In almost all advanced economies the marginal tax rate increases with income and public transfers are targeted to disadvantaged groups including low income households, the sick and the unemployed. As a result, tax systems and social insurance systems tend to be highly progressive as a whole and play a key role in shaping the income distribution across households and over time. In this paper we quantitatively characterize the optimal progressivity of the U.S. income tax system in a lifecycle framework where income and health risks are present simultaneously.

Our framework is based on two workhorse models in the literature: the Bewley model with idiosyncratic income risk and incomplete markets (Bewley (1986)) and the Grossman model of health capital accumulation (Grossman (1972a)). In a Bewley environment with idiosyncratic income risk, progressive income taxation can potentially increase welfare in two ways. First, progressive taxes lead to a more equal distribution of income and therefore to more equitable distributions of wealth and consumption. Second, in the absence of private insurance markets, progressive taxes provide a partial insurance substitute and can generate more stable household consumption paths over time through income redistribution from “lucky” individuals to “unlucky” ones who experience large negative shocks to income. Interestingly, many aspects of health risk and health insurance policies are largely absent in the literature on social insurance.

On the other hand, in a Grossman environment where individuals value their health in addition to a consumption goods basket, a strong motive exists to smooth both health and the consumption bundle over the lifecycle. Health affects household consumption in two ways. First, the utility of consumption itself is affected by the health status of an individual. Second, health is a co-determinant of labor earnings and therefore affects the household’s ability to purchase final consumption goods. In addition, smoothing health over the lifecycle requires healthcare spending. These funds are subsequently lost for purchasing final consumption goods. The simultaneous presence of both income and health risks and the institutional insurance arrangements that lower the household’s exposure to such risk shape the distributions of income, wealth and consumption. In this environment both progressive taxes and public health insurance play a role in providing social insurance.

The main goal of the paper is to formulate a comprehensive framework that contains essential features of the Bewley and Grossman models and analyzes the optimal design of a progressive income tax system in the presence of a mixed public and private health insurance system similar to the U.S. system. This modeling framework allows us to model the lifecycle structure of health risk in conjunction with income risk as observed in the data. In the model, health care spending and health insurance take-up rates over the lifecycle are endogenous and jointly determined with
consumption, savings and the supply of labor.

In order to gain understanding of the underlying economic incentives, we first start with a simple partial equilibrium model with both income and health risk and illustrate the channels through which the optimal degree of income tax progressivity depends on the joint distribution of income and health risks over the lifecycle. Next, we turn to the full dynamic general equilibrium model and calibrate it to match the structure of income and health risk observed in U.S. data. The benchmark model incorporates the lifecycle patterns of shocks to income and health and matches the labor supply, asset holdings, consumption and health expenditures in the U.S. Health expenditures are low early in life because of high initial health capital and low health risk. Health expenditures rise exponentially later in life because individuals are exposed to more frequent and larger health shocks. Our benchmark model also reproduces the hump-shaped lifecycle profile of insurance take-up rates, the income distribution from the Panel of Income Dynamics (PSID) as well as macroeconomic aggregates from national income accounts (NIPA). We use the calibrated model to quantitatively explore the shape of the optimal progressivity of income taxes in the U.S. Our results are summarized as follows:

First, the optimal income tax system is highly progressive and imposes a tax break for income below US$ 38,000, followed by a jump in the marginal tax rate to 25 percent. The marginal tax rate then increases further to over 40 percent for income above US$ 100,000 and to over 50 percent for income above US$ 200,000. Aggregate labor supply and household savings of high income households are not strongly affected by high marginal tax rates due to strong precautionary motives. The optimal tax system in our model is different from the optimal tax systems found in prior literature that abstracts from health risk and health insurance institutions (e.g., Conesa and Krueger (2006) and Heathcote, Storesletten and Violante (2016)).

In order to measure the progressive level of the U.S. income tax system, we follow Suits (1977) and compute the Suits index—a Gini coefficient for income tax contributions by income. The Suits index varies from +1 (most progressive) where the entire tax burden is allocated to households of the highest income bracket, through 0 for a proportional tax, to −1 (most regressive) at which the entire tax burden is allocated to households of the lowest income bracket. We calculate a Suits index of 0.17 for the current U.S. tax system calibrated to data from 2010. The optimal tax system is much more progressive with a Suits index of 0.54.

With optimal progressive taxes income inequality decreases significantly. We observe that the after-tax-income Gini coefficient decreases from 0.38 in the benchmark economy to 0.31 in the economy with optimized progressivity. We observe large welfare gains of 5.5 percent of compensating lifetime consumption at the aggregate level when switching from the benchmark to the optimal tax system. This outcome is mainly driven by large welfare gains of low income individuals which dominate the welfare losses of high income groups.

We then analyze how changes in health insurance policy affect the optimal level of tax progressivity and use the Affordable Care Act (ACA) as a demonstration case. The ACA provides channels that redistribute resources from healthy high income types to sicker low income types through premium subsidies and an expansion of Medicaid—a public health insurance program
for low income individuals. Our results show that with the ACA the optimal tax progressivity decreases slightly. The suits index drops to 0.52.

Finally, we examine how the parametric specification of the income tax function affects the optimal tax progressivity. We compare the two commonly used specifications. The first is based on the two parameter specification from Benabou (2002) which has been used more recently in Heathcote, Storesletten and Violante (2016) and the second is based on the three parameter specification from Gouveia and Strauss (1994) which was used in Conesa and Krueger (2006). The shapes of the optimal tax function differ significantly and welfare gains from optimizing progressivity using the three parameter specification are smaller at 1.08 percent of compensating lifetime consumption compared to 5.5 percent with the 2-parameter polynomial. In addition, the transfer policy to the low income households at the bottom of the distribution strongly affects the shape of the optimal marginal tax function. Our findings indicate that the parametric specification of the tax function as well as the design of transfer policies are important for evaluating the optimal level of progressivity of the income tax code.

**Related Literature.** Our work is connected to different branches of the quantitative macroeconomics and health economics literature. First, our paper is related to the literature on incomplete markets macroeconomic models with heterogeneous agents as pioneered by Bewley (1986) and extended by Huggett (1993) and Aiyagari (1994). This Bewley model has been applied widely to quantify the welfare cost of public insurance for idiosyncratic income risk (e.g., Hansen and Imrohoroglu (1992), Imrohoroglu, Imrohoroglu and Joines (1995), Golosov and Tsyvinski (2006), Heathcote, Storesletten and Violante (2008), Conesa, Kitao and Krueger (2009) and Huggett and Parra (2010)). This literature focuses on the welfare cost triggered by income risk in combination with a lack of insurance for non-medical consumption. Recently, Capatina (2015) demonstrates that health shocks are another important source of idiosyncratic risk faced by individuals over the lifecycle. In this paper, we contribute to this literature by incorporating health risk and medical consumption into a Bewley framework in order to analyze the optimal income tax progressivity in the presence of health insurance similar to the U.S.

Second, our work contributes to a growing macro-public finance literature that extends the Grossman model of health capital accumulation (Grossman (1972a)). This literature incorporates health shocks, insurance markets and general equilibrium channels using a more realistic institutional setting (e.g., Jung and Tran (2007), Yogo (2009), Fonseca et al. (2013), Scholz and Seshadri (2013a) and Jung and Tran (2016)). Jung and Tran (2015) explore the welfare implications of optimal health insurance policies in a dynamic general equilibrium model of health capital accumulation. In this paper, we quantitatively characterize the optimal progressivity of the income tax system, taking into account the redistribution effects of the health insurance system and demonstrate the effects of changes in the health insurance system on the optimal tax progressivity.

Third, our paper is closely related to the optimal progressive income taxation literature. Conesa and Krueger (2006) quantify the optimal progressivity of the income tax code in a dynamic general equilibrium model with household heterogeneity due to uninsurable labor pro-
ductivity risk. They show that a progressive tax system serves as a partial substitute for missing income-insurance markets and results in a more equal distribution of income. Erosa and Koreshkovka (2007) analyze the insurance role of the U.S. progressive income tax code in a dynastic model with human capital accumulation. Chambers, Garriga and Schlaginhauf (2009) quantify interactions between progressive income taxes and housing policies to promote homeowners in an overlapping generations model with housing and rental markets. Krueger and Ludwig (2016) compute the optimal tax- and education policy in an economy where progressive taxes provide social insurance against idiosyncratic wage risk, but distort the education and human capital decision of households. Stantcheva (2015) characterizes the optimal income tax and human capital policies in a dynamic lifecycle model of labor supply with risky human capital formation. Heathcote, Storesletten and Violante (2016) develop an analytical framework for studying optimal tax progressivity. McKay and Reis (2016) study the optimal generosity of unemployment benefits and progressivity of income taxes in a model with individual unemployment risks and macroeconomic aggregate shocks. Note that previous studies abstract from health risk and the implications of health insurance on the design of an optimized income tax system, which is the focus of this paper. We re-visit the optimal taxation problem in a relatively new environment where health is a key source of agent heterogeneity and income inequality. In addition, we account for the significant amount of social insurance that the U.S. health insurance system already provides when optimizing the progressivity of the income tax system.

Finally, our paper is connected to the literature on high marginal tax rates for top income earners. Diamond and Saez (2011) advocates for taxing labor earnings at the high end of the distribution at very high marginal rates in excess of 75 percent. Badel and Huggett (2014) assess the consequences of increasing the marginal tax rate on U.S. top income earners using a human capital model. Guner, Lopez-Daneri and Ventura (2016) analyze how effective a progressive income tax system is in raising tax revenues. Kindermann and Krueger (2015) find high marginal labor income tax rates are an effective tool for social insurance in a large-scale stochastic overlapping generations model with optimal marginal tax rates for top 1 percent earners of close to 90 percent. Different from these studies, we focus on the optimal marginal tax rates across the entire income distribution. Moreover, we base our analysis on a health capital model where health risk is an additional source of heterogeneity next to labor market risk. We also find that very high tax rates at the top are an essential component of the optimal progressive tax system. More importantly, we highlight that such high optimal marginal tax rates at the top are inter-dependent with the marginal tax rates set at the bottom of the income distribution and the government transfer policies already in place.

The paper is structured as follows. Section 2 describes the insurance and incentive trade-off in a two-period model. Section 3 presents the full dynamic model. Section 4 describes our calibration strategy. Section 5 describes our experiments and quantitative results. Section 6 concludes. The Appendix presents all calibration tables and figures.
2 The Simple Model

2.1 Environment

Endowments and Preferences. Individuals live for two periods with certainty. They supply labor elastically in period 1 and do not work in period 2. In period 2 the individual faces uncertain income levels $\epsilon_I$ as well as health expenditure shocks $\epsilon_H$. These shocks are drawn from a joint distribution

$$
\begin{bmatrix}
\epsilon_I \\
\epsilon_H
\end{bmatrix}
\sim \text{Dist}
\begin{bmatrix}
\mu_I \\
\mu_H
\end{bmatrix}
, 
\begin{bmatrix}
\sigma_I^2 & \sigma_{IH} \\
\sigma_{IH} & \sigma_H^2
\end{bmatrix},
$$

with density $f(\epsilon_I, \epsilon_H)$ where $\mu_I = 0$ and $\mu_H > 0$ and $\sigma_I^2 > 0$, $\sigma_H^2 > 0$ and $\sigma_{IH} > 0$. Health shocks will result in compulsory health care expenditures. Individuals derive utility from consumption in both periods and disutility from work in period 1. Their lifetime utility is $u(c_1) - \phi v(n) + \beta E[u(c_2)]$, where $u(.)$ and $v(.)$ are utility functions with the usual properties, $c_1$ and $c_2$ are consumption in periods 1 and 2, respectively, $n$ is labor supply, $\phi$ scales the level of disutility of labor, $\beta$ is the time discount factor and $E$ is the expectations operator.

Government. The government runs two separate transfer programs. The first is a transfer program financed by a payroll tax $\tau_I$ which pays a lump-sum payment of $d$ in the second period. The second program is a health insurance program that pays a fraction $1 - \rho$ of the health care expenditures $\epsilon_H$ and is financed by a payroll tax $\tau_H$.

Household Problem. The household maximization problem can be summarized as

$$
\max_{\{c_1, c_2, n, s\}} \left\{ u(c_1) - \phi v(n) + \beta E[u(c_2)] \right\} \text{ s.t.}
$$

$$
c_1 + s = (1 - \tau_I - \tau_H) wn, 
$$

$$
c_2 + \rho \epsilon_H = Rs + d + \epsilon_I,
$$

where $w$ is the wage rate, $R$ is the interest rate, $s$ is savings in period 1, $d$ is the lump-sum transfer and $\rho$ is the coinsurance rate. The first order conditions are

$$
\partial n : u'(c_1) (1 - \tau_I - \tau_H) w = \phi v'(n), 
$$

$$
\partial s : u'(c_1) = \beta RE [u'(c_2)] .
$$

Government Problem. The government clears the two programs separately so that

$$
\tau_I wn = \int_{\epsilon_H} \int_{\epsilon_I} (1 - \rho) \epsilon_H f(\epsilon_I, \epsilon_H) d\epsilon_I d\epsilon_H = (1 - \rho) \mu_H ,
$$

$$
\tau_I wn = \int_{\epsilon_H} \int_{\epsilon_I} d \times f(\epsilon_I, \epsilon_H) d\epsilon_I d\epsilon_H := D ,
$$
or
\[ \tau_H = \frac{(1 - \rho) \mu_H}{wn}, \quad (3) \]
\[ \tau_I = \frac{D}{wn}. \quad (4) \]

The government maximizes the following problem
\[
V(\tau_I, \rho) = \max_{\tau_I, \rho} \{ u(wn(1 - \tau_I - \tau_H) - s) - \phi v(n) + \beta E[u(Rs + d + \epsilon_I - \rho \epsilon_H)] \}
\]
\[ s.t. (1), (2), (3) \text{ and } (4). \]

When the government chooses \( \tau_I \) and \( \rho \) via expressions (3) and (4) respectively, it automatically fixes \( D \) and \( \tau_H \). Since the population in each period is normalized to one we also have that \( d = D \).

### 2.2 Optimal Taxation and Insurance Policy

The government first order conditions are
\[
\frac{\partial V}{\partial \rho} = u'(c_1) \left[ w \left( \frac{\partial n}{\partial \rho} (1 - \tau_I - \tau_H) - n \frac{\partial \tau_H}{\partial \rho} \right) - \frac{\partial s}{\partial \rho} \right] - \phi'v(n) \frac{\partial n}{\partial \rho} + \beta E \left[ u'(c_2) \left( R \frac{\partial s}{\partial \rho} + \frac{\partial d}{\partial \rho} - \epsilon_H \right) \right],
\]
\[ (5) \]
\[
\frac{\partial V}{\partial \tau_I} = u'(c_1) \left[ w \left( \frac{\partial n}{\partial \tau_I} (1 - \tau_I - \tau_H) - n \right) - \frac{\partial s}{\partial \tau_I} \right] - \phi'v(n) \frac{\partial n}{\partial \tau_I} + \beta E \left[ u'(c_2) \left( R \frac{\partial s}{\partial \tau_I} + \frac{\partial d}{\partial \tau_I} \right) \right],
\]
\[ (6) \]

where we know from expressions (3) and (4) that
\[
\frac{\partial \tau_H}{\partial \rho} = -\frac{\mu_H}{wn} \left( n + (1 - \rho) \frac{\partial n}{\partial \rho} \right),
\]
\[
\frac{\partial D}{\partial \tau_I} = w \left( n + \tau_I \frac{\partial n}{\partial \tau_I} \right),
\]
\[
\frac{\partial D}{\partial \rho} = \tau_I w \frac{\partial n}{\partial \rho}.
\]

Substituting these expressions and the firm FOCs into the government FOCs (5) and (6) we get two government Euler equations
\[
\frac{\partial V}{\partial \rho} = u'(c_1) \mu_H \left( n + (1 - \rho) \frac{\partial n}{\partial \rho} \right) + \beta E \left[ u'(c_2) \left( \tau_I w \frac{\partial n}{\partial \rho} - \epsilon_H \right) \right] = 0,
\]
\[
\frac{\partial V}{\partial \tau_I} = -u'(c_1) wn + \beta E \left[ u'(c_2) w \left( n + \tau_I \frac{\partial n}{\partial \tau_I} \right) \right] = 0.
\]
This system describes the trade-off between current cost and future benefits of changes in the replacement rate $\rho$ and the labor tax rate $\tau_n$ which finances lump-sum transfers in the second period.

Our analysis indicates that the optimal income tax rate depends not only on the joint-distribution of health and income shocks but also on the level of progressivity of the health insurance program. The optimal design of the optimal progressive income tax system depends on economy-based fundamentals including preferences, the evolution of income and health risks over the lifecycle, and the structure of the existing health insurance system. In the next section, we formulate a more realistic model of the U.S. economy. We then quantify the optimal level of income tax progressivity for differently designed health insurance systems.

3 The Full Model

3.1 Technologies and Firms

There are two production sectors in the economy, which are assumed to grow at a constant rate $g$. Sector one is populated by a continuum of identical firms that use physical capital $K$ and effective labor services $N$ to produce a non-medical consumption good $c$ with a normalized price of one. Firms in the non-medical sector are perfectly competitive and solve the following maximization problem

$$\max_{\{K, N\}} F(K, N) - qK - wN, \tag{7}$$

taking the rental rate of capital $q$ and the wage rate $w$ as given. Capital depreciates at rate $\delta$ in each period. Sector two, the medical sector, is also populated by a continuum of identical firms that use capital $K_m$ and labor $N_m$ to produce medical services $m$ at a price of $p_m$. Firms in the medical sector maximize

$$\max_{\{K_m, N_m\}} p_m F_m (K_m, N_m) - qK_m - wN_m. \tag{8}$$

3.2 Demographics, Preferences and Endowments

The economy is populated with overlapping generations of individuals who live up to a maximum of $J$ periods. Individuals work for $J_1$ periods and are retired thereafter. Individuals survive each period with age dependent survival probability $\pi_j$. Deceased agents leave an accidental bequest that is taxed and redistributed equally to the working age population. The population grows exogenously at an annual rate $n$. We assume stable demographic patterns, so that age $j$ agents make up a constant fraction $\mu_j$ of the entire population at any point in time. The relative sizes of the cohorts alive $\mu_j$ and the mass of individuals dying in each period $\tilde{\mu}_j$ (conditional on survival up to the previous period) can be recursively defined as $\mu_j = \frac{\pi_j}{1+n} \mu_{j-1}$ and $\tilde{\mu}_j = 1 - \frac{1-\pi_j}{1+n} \mu_{j-1}$, where years denotes the number of years per model period.

In each period individuals are endowed with one unit of time that can be used for work $n$ or leisure. Individual utility is denoted by function $u(c, n, h)$ where $u: R^3_+ \to R$ is $C^2$, increases
in consumption $c$ and health $h$, and decreases in labor $n$. We assume a Cobb-Douglas type utility function of the form
\[
    u(c,n,h) = \left( \frac{c^\eta (1 - n - 1_{[n>0]}\bar{n}_j)^{1-\eta} \times h^{1-\kappa}}{1-\sigma} \right)^{1-\sigma},
\]
where $\bar{n}_j$ is an age dependent fixed cost of working as in French (2005), $\eta$ is the intensity parameter of consumption relative to leisure, $\kappa$ is the intensity parameter of health services relative to consumption and leisure, and $\sigma$ is the inverse of the inter-temporal rate of substitution (or relative risk aversion parameter).

Individuals are born with a specific skill type $\vartheta$ that cannot be changed and that together with their health capital $h_j$ and an idiosyncratic labor productivity shock $\epsilon_n^j$ determines their age-specific labor efficiency $e_j(\vartheta, h_j, \epsilon_n^j)$. The transition probabilities for the idiosyncratic productivity shock $\epsilon_n^j$ follow an age-dependent Markov process with transition probability matrix $\Pi_n^j$. An element of this transition matrix is defined as the conditional probability $\Pr(\epsilon_n^{i+1}|\epsilon_n^i)$, where the probability of next period’s labor productivity $\epsilon_n^{i+1}$ depends on today’s productivity shock $\epsilon_n^i$.

### 3.3 Health Capital

Health capital evolves according to $h_j = H(m_j, h_{j-1}, \delta^h_j, \epsilon^h_j)$, where $h_j$ denotes current health capital, $h_{j-1}$ denotes health capital of the previous period, $\delta^h_j$ is the depreciation rate of health capital and $\epsilon^h_j$ is an idiosyncratic health shock. The exogenous health shock $\epsilon^h_j$ follows a Markov process with age dependent transition probability matrix $\Pi^h_j$. Transition probabilities to next period’s health shock $\epsilon^{h+1}_j$ depend on the current health shock $\epsilon^h_j$ so that an element of transition matrix $\Pi^h_j$ is defined as the conditional probability $\Pr(\epsilon^{h+1}_j|\epsilon^h_j)$. Individuals can buy medical services $m_j$ at price $p_m$ to improve their health capital. Specifically, the law of motion of health capital follows
\[
    h_j = \phi_j m_j^\xi + (1 - \delta^h_j) h_{j-1} + \epsilon^h_j.
\]
This law of motion is an extension of the deterministic framework in Grossman (1972a). The first two components are indeed similar to the original deterministic form in Grossman (1972a); meanwhile, the third component can be thought of as a random depreciation rate as in Grossman (2000).

\footnote{Heathcote, Storesletten and Violante (2016) allow public goods to enter the preferences directly. In their setting, the utility from consumption of public goods and risk sharing are two main channels of welfare gains. In our analysis, we abstract from the former and focus on the latter. Thus, our approach is similar to Conesa and Krueger (2006).}
3.4 Health Insurance

In the benchmark economy we introduce the main features of the U.S. health insurance system before the implementation of the Affordable Care Act in 2010. The health insurance market consists of private health insurance companies that offer two types of health insurance policies: (i) an individual health insurance plan (IHI) and (ii) a tax deductible group health insurance plan (GHI). Individuals are required to buy insurance one period prior to the realization of their health shock in order to be insured in the following period. The insurance policy needs to be renewed each period. By construction, agents in their first period are thus not covered by any insurance. The government provides public health insurance with Medicaid for the poor and Medicare for retirees. To be eligible for Medicaid, individuals are required to pass an income and asset test. The health insurance state $in_j$ for workers can therefore take on the following values:

$$in_j = \begin{cases} 
0 & \text{not insured}, \\
1 & \text{Individual health insurance (IHI),} \\
2 & \text{Group health insurance (GHI),} \\
3 & \text{Medicaid.} 
\end{cases}$$

After retirement ($j > J_1$) all agents are covered by public health insurance which is a combination of Medicare and Medicaid for which they pay a premium, $\text{prem}^R$.

An agent’s total health expenditure in any given period is $p_{in}^{mj} \times m_j$, where the price of medical services $p_{in}^{mj}$ depends on insurance state $in_j$. The out-of-pocket health expenditure of a working-age agent is given by

$$o(m_j) = \begin{cases} 
p_{in}^{mj} \times m_j, & \text{if } in_j = 0, \\
p_{in}^{mj} \times \left( p_{in}^{mj} \times m_j \right), & \text{if } in_j > 0 
\end{cases}$$

where $0 \leq \rho_{in}^{mj} \leq 1$ are the insurance state specific coinsurance rates. The coinsurance rate denotes the fraction of the medical bill that the patient has to pay out-of-pocket.\footnote{For simplicity we include deductibles and co-pays into the coinsurance rate.} A retiree’s out-of-pocket expenditure is $o(m_j) = \rho^R \times \left( p^R_{m} \times m_j \right)$, where $\rho^R$ is the coinsurance rate of Medicare and $p^R_{m}$ is the price that a Medicare patient pays for medical services.

**Insurance Companies.** Insurance companies offer IHI to any working individual and charge an age and health dependent premium, $\text{prem}^{\text{IHI}}(j,h)$. In addition, workers are randomly assigned to employers who offer GHI which is indicated by random variable $\epsilon^{\text{GHI}} = 1$. The GHI premium, $\text{prem}^{\text{GHI}}$, is tax deductible and group rated so that insurance companies are not allowed to screen workers by health or age. If a worker is not offered group insurance from her employer, i.e., $\epsilon^{\text{GHI}} = 0$, the worker can still buy IHI. However, the worker is subjected to screening and the insurance premium is not tax deductible. There is a Markov process that governs the group insurance offer probability. It is a function of the individual’s permanent skill type $\vartheta$. Let $\Pr \left( \epsilon^{\text{GHI}}_{j+1} | \epsilon^{\text{GHI}}_j, \vartheta \right)$ be the conditional probability that an agent has group insurance status $\epsilon^{\text{GHI}}_{j+1}$ at age $j+1$ given she had group insurance status $\epsilon^{\text{GHI}}_j$ at age $j$. All conditional
probabilities for group insurance status are collected in a $2 \times 2$ transition probability matrix $\Pi_{j,0}^{GHI}$.

For simplicity we abstain from modeling insurance companies as profit maximizing firms and simply allow for a premium markup $\omega$. Since insurance companies in the individual market screen customers by age and health, we impose separate clearing conditions for each age-health type, so that premiums, $\text{prem}^{\text{HH}}(j, h)$, adjust to balance

$$
(1 + \omega_{j,h}^{\text{HH}}) \mu_j \int \left[ 1_{[\text{in}_j(x_j,h)=1]} \left( 1 - \rho_{j,h}^{\text{HH}} \right) p_{m}^{\text{HH}} m_{j,h}(x_j,h) \right] d\Lambda(x_j,-h)
$$

$$
= R \mu_{j-1} \int \left( 1_{[\text{in}_{j-1}(x_{j-1},h)=1]} \text{prem}_{j-1}^{\text{HH}} (j-1, h) \right) d\Lambda(x_{j-1},-h),
$$

where $x_{j,-h}$ is the state vector for cohort age $j$ not containing $h$ since we do not want to aggregate over the health state vector $h$ in this case. The clearing condition for the group health insurances is simpler as only one price, $\text{prem}^{\text{GHI}}$, adjusts to balance

$$
(1 + \omega_{j,h}^{\text{GHI}}) \sum_{j=2}^{J_1} \mu_j \int \left[ 1_{[\text{in}_j(x_j)=2]} \left( 1 - \rho_{j}^{\text{GHI}} \right) p_{m}^{\text{GHI}} m_{j}(x_j) \right] d\Lambda(x_j)
$$

$$
= R \sum_{j=1}^{J_1-1} \mu_j \int \left( 1_{[\text{in}_j(x_j)=2]} \text{prem}^{\text{GHI}} \right) d\Lambda(x_j),
$$

where $\omega_{j,h}^{\text{HH}}$ and $\omega_{j,h}^{\text{GHI}}$ are markup factors that determine loading costs (fixed costs or profits). Variables $\rho_{j,h}^{\text{HH}}$ and $\rho_{j}^{\text{GHI}}$ are the coinsurance rates, and $p_{m}^{\text{HH}}$ and $p_{m}^{\text{GHI}}$ are the prices for health care services of the two insurance types. The respective left-hand-sides in the above expressions summarize aggregate payments made by insurance companies whereas the right-hand-sides aggregate the premium collections one period prior. Since premiums are invested for one period, they enter the capital stock and we therefore multiply the term with the after tax gross interest rate $R$. The premium markups generate profits which are redistributed in equal (per-capita) amounts of $\pi^{\text{profits}}$ to all surviving agents.\textsuperscript{3}

### 3.5 Fiscal Policy

The government administers various government programs that are financed by a combination of taxes.

**Progressive Income Taxes.** The progressive income tax function has the following specification

$$
\tilde{\tau}(\tilde{y}) = \max \left[ 0, \tilde{y} - a_0 \times \tilde{y}^{(1-a_1)} \right],
$$

\textsuperscript{3}Notice that ex-post moral hazard and adverse selection issues arise naturally in the model due to information asymmetry. Insurance companies cannot directly observe the idiosyncratic health shocks and have to reimburse agents based on the actual observed levels of health care spending. Adverse selection arises because insurance companies cannot observe the risk type of agents and therefore cannot price insurance premiums accordingly. They instead have to charge an average premium that clears the insurance companies’ profit conditions. Individual insurance contracts do distinguish agents by age and health status but not by their health shock.
where $\tilde{\tau}(\tilde{y})$ denotes net tax revenues as a function of pre-tax income $\tilde{y}$, $a_1$ is the progressivity parameter, and $a_0$ is a scaling factor to match the U.S. income tax revenue. This tax function is fairly general and captures the common cases:

\[
\begin{align*}
(1) \text{ Full redistribution: } & \quad \tilde{\tau}(\tilde{y}) = \tilde{y} - a_0 \quad \text{and} \quad \tilde{\tau}'(\tilde{y}) = 1 & \quad \text{if } a_1 = 1, \\
(2) \text{ Progressive: } & \quad \tilde{\tau}'(\tilde{y}) = 1 - (1 - a_1)a_0\tilde{y}(a_1) \quad \text{and} \quad \tilde{\tau}'(\tilde{y}) > \frac{\tilde{\tau}(\tilde{y})}{\tilde{y}} & \quad \text{if } 0 < a_1 < 1, \\
(3) \text{ No redistribution (proportional): } & \quad \tilde{\tau}(\tilde{y}) = \tilde{y} - a_0\tilde{y} \quad \text{and} \quad \tilde{\tau}'(\tilde{y}) = 1 - a_0 & \quad \text{if } a_1 = 0, \\
(4) \text{ Regressive: } & \quad \tilde{\tau}(\tilde{y}) = 1 - (1 - a_1)a_0\tilde{y}(a_1) \quad \text{and} \quad \tilde{\tau}'(\tilde{y}) < \frac{\tilde{\tau}(\tilde{y})}{\tilde{y}} & \quad \text{if } a_1 < 0.
\end{align*}
\]

We impose a non-negative tax payment restriction in the benchmark model, $\tilde{\tau}(\tilde{y}) \geq 0$. This restriction excludes all government transfers embedded in the progressive tax function. Government transfers are explicitly modeled in government spending programs.\(^4\)

**Spending.** The government finances the following programs: social security, social transfers to low income earners, public health insurance, and general government consumption. The social security program operates on a Pay-As-You-Go (PAYG) principle in which the government collects a payroll tax $\tau_{SS}$ from the working population to finance social security benefits $t_{SS}$ for retired individuals. The PAYG program is self-financed. In addition, the government provides social insurance through a social transfer program ($T_{SI}$) that guarantees a minimum consumption level. Public health insurance consists of Medicare and Medicaid. Medicare is financed by a Medicare tax ($tax_{j}^{Med}$) and premium payments ($prem_{j}^{R}$) and Medicaid is financed by general tax revenues. In addition, the government needs to finance government consumption ($C_G$) which is exogenous and unproductive. Finally, the government collects accidental bequests from deceased individuals and redistributes them as lump-sum payments $t_{J}^{Beq}$ to all surviving working-age households.

**Balanced Budget.** The government collects consumption tax revenue at a flat rate, $\tau^C$, and income tax revenue at a progressive rate to balance its budget every period. The government budget constraint is given by

\[
C_G + T_{SI} + \sum_{j=2}^{J_1} \mu_j \int 1_{[in_{j}(x_j) = 3]} (1 - \rho_{MAid}^M) p_{m}^{MAid} m_{j}(x_j) \ d\Lambda(x_j) + \sum_{j=J_1+1}^{J} \mu_j \int (1 - \rho^R) p_{m}^R m_{j}(x_j) \ d\Lambda(x_j) = \sum_{j=1}^{J} \mu_j \int [\tau^C c(x_j) + tax_{j}(x_j)] \ d\Lambda(x_j) + \sum_{j=J_1+1}^{J} \mu_j \int prem_{j}(x_j) \ d\Lambda(x_j) + \sum_{j=1}^{J_1} \mu_j \int tax_{j}^{Med} \ d\Lambda(x_j),
\]

where $\rho_{MAid}^M$ and $\rho^R$ are the coinsurance rate of Medicaid and of the combined Medicare/Medicaid

\(^4\)This tax function was implemented into a dynamic setting by Benabou (2002) and more recently in Heathcote, Storesletten and Violante (2016). These authors do not model transfers explicitly and therefore allow income taxes to become negative for low income groups.
program for the old, respectively.

3.6 Household Problem

Individuals at age $j \leq J_1$ are workers and thus exposed to labor shocks. Old individuals, $j > J_1$, are retired ($n_j = 0$) and receive pension payments. They do not face labor market shocks anymore. The agent state vector at age $j$ is given by

$$
\begin{align*}
x_j \in D_j \equiv \begin{cases} 
(a_j, h_{j-1}, \vartheta, \epsilon^n_j, \epsilon^h_j, \text{in}_j) \in R_+ \times R_+ \times R_+ \times R_+ \times \mathbb{I}^w & \text{if } j \leq J_1, \\
(a_j, h_{j-1}, \vartheta, \epsilon^n_j, \text{in}_j) \in R_+ \times R_+ \times R_+ \times R_+ \times \mathbb{I}^R & \text{if } j > J_1,
\end{cases}
\end{align*}
$$

where $a_j$ is the capital stock at the beginning of the period, $h_{j-1}$ is the health state at the beginning of the period, $\vartheta$ is the skill type, $\epsilon^n_j$ is the positive labor productivity shock, $\epsilon^h_j$ is a negative health shock, $\text{in}_j$ is the insurance state and $\mathbb{I}^w = \{0, 1, 2, 3\}$ denotes the dimension of the insurance state of workers and $\mathbb{I}^R = \{1\}$ is the sole insurance state for retirees as every retiree is on a combined Medicare/Medicaid program. After the realization of the state variables, agents simultaneously chose from their choice set

$$
\begin{align*}
\mathcal{C}_j \equiv \begin{cases} 
(c_j, n_j, m_j, a_{j+1}, \text{in}_{j+1}) \in R_+ \times [0, 1] \times R_+ \times R_+ \times \mathbb{I}^w & \text{if } j \leq J_1, \\
(c_j, m_j, a_{j+1}) \in R_+ \times R_+ \times R_+ & \text{if } j > J_1,
\end{cases}
\end{align*}
$$

where $c_j$ is consumption, $n_j$ is labor supply, $m_j$ are health care services, $a_{j+1}$ are asset holdings for the next period and $\text{in}_{j+1}$ is the insurance state for the next period in order to maximize their lifetime utility. All choice variables in the household problem depend on state vector $x_j$. We suppress this dependence in the notation to improve readability. The household optimization problem is

$$
V(x_j) = \max_{\{c_j\}} \{u(c_j, n_j, h_j) + \beta \pi_j E[V(x_{j+1}) | x_j]\} \quad \text{s.t.} \quad (15)
$$

$$
(1 + \tau^C) c_j + (1 + g) a_{j+1} + o(m_j)
+ 1_{[j \leq J_1 \land \text{in}_{j+1} = 1]} \text{prem}^{\text{HHI}}(j, h) + 1_{[j \leq J_1 \land \text{in}_{j+1} = 2]} \text{prem}^{\text{GHI}} + 1_{[j > J_1]} \text{prem}^R
= y_j - \text{tax}_j + \text{SI}_j,
0 \leq a_{j+1}, \ 0 \leq n_j \leq 1 \text{ and (9)}.
$$

Variable $\tau^C$ is a consumption tax rate, $o(m_j)$ is out-of-pocket medical spending depending on insurance type, $y^w_j$ is the sum of all income including labor, assets, bequests, and profits.
Household income and tax payments are defined as

\[ y_j = e(\vartheta, h_j, \varepsilon^j_n) n_j w + 1_{j > JW}t^{soc}_j(\vartheta) + R(a_j + t^{Beq}) + \pi^{profits}, \]

\[ \text{tax}_j = \tilde{\tau}(\tilde{y}_j) + \text{tax}^{SS}_j + \text{tax}^{Mcare}_j, \]

\[ \tilde{y}_j = y_j - a_j - t^{Beq} - 1_{[in_j+1=2]}\text{prem}^{GHI} - 0.5(\text{tax}^{SS}_j + \text{tax}^{Med}_j), \]

\[ \text{tax}^{SS}_j = \tau^{Soc} \times \min \left( \tilde{y}^{ss}, e(\vartheta, h_j, \varepsilon^j_n) n_j w - 1_{[in_j+1=2]}\text{prem}^{GHI} \right), \]

\[ \text{tax}^{Mcare}_j = \tau^{Mcare} \times \left( e(\vartheta, h_j, \varepsilon^j_n) n_j w - 1_{[in_j+1=2]}\text{prem}^{GHI} \right), \]

\[ t^{SI}_j = \max [0, \zeta + o(m_j) + \text{tax}_j - y_j]. \]

Variable \( w \) is the market wage rate and \( R \) is the gross interest rate and \( \pi^{profits} \) denotes profits from insurance companies. Variable \( \tilde{y}_j \) is taxable income, \( \tilde{\tau}(\tilde{y}_j) \) is the progressive income tax payment and \( \text{tax}^{SS}_j \) is the social security tax with marginal rate \( \tau^{SS} \) that finances the social security payments \( t^{SS}_j \). The maximum contribution to social security is \( \tilde{y}^{ss} \). The social insurance payment \( t^{SI}_j \) guarantees a minimum consumption level \( \zeta \). If social insurance is paid out, then automatically \( a_{j+1} = 0 \), so that social insurance cannot be used to finance savings.

For each \( x_j \in D_j \) let \( \Lambda(x_j) \) denote the measure of age \( j \) agents with \( x_j \in D_j \). Then expression \( \mu_j \Lambda(x_j) \) becomes the population measure of age-\( j \) agents with state vector \( x_j \in D_j \) that is used for aggregation.

4 Calibration

For the calibration we distinguish between two sets of parameters: (i) externally selected parameters and (ii) internally calibrated parameters. Externally selected parameters are estimated independently from our model and are either based on our own estimates using data from the Medical Expenditure Panel Survey (MEPS) or estimates provided by other studies. We summarize these external parameters in Table 1. Internal parameters are calibrated so that model-generated data match a given set of targets from U.S. data. These parameters are presented in Table 2. Model generated data moments and target moments from U.S. data are juxtaposed in Table 3.\(^5\)

4.1 Technologies and Firms

We impose a Cobb-Douglas production technology using physical capital and labor as inputs for the final goods and the medical sector respectively: \( F(K, N) = AK^\alpha N^{1-\alpha} \) and \( F_m(K_m, N_m) = A_m K_m^{\alpha_m} N_m^{1-\alpha_m} \). We set the capital share \( \alpha = 0.33 \) and the annual capital depreciation rate at \( \delta = 0.1 \). They are both similar to standard values in the calibration literature (e.g., Kydland and Prescott (1982)). The capital share in production in the health care sector is lower at \( \alpha_m = 0.26 \) which is based on Donahoe (2000) and our own calculations. We abstract from

\(^5\)More details of our calibration strategy and the solution algorithm can be found in Jung and Tran (2016).
changes in production technologies or other possible causes of excess cost growth in the U.S. health sector.

4.2 Demographics, Preferences and Endowments

One model period is defined as 5 years. We model households from age 20 to age 95 which results in $J = 15$ periods. The annual conditional survival probabilities, supplied by CMS, are adjusted for period length. The population growth rate for the U.S. was 1.2 percent on average from 1950 to 1997 according to the Council of Economic Advisors (1998). In the model the total population over the age of 65 is 17.7 percent which is very close to the 17.4 percent in the census.

We choose fixed cost of working, $\bar{n}_j$, to match labor hours per age group. Parameter $\sigma = 3.0$ and the time preference parameter $\beta = 1.001$ to match the capital output ratio and the interest rate. The intensity parameter $\eta$ is 0.43 to match the aggregate labor supply and $\kappa$ is 0.89 to match the ratio between final goods consumption and medical consumption. In conjunction with the health productivity parameters $\phi_j$ and $\xi$ from expression (9) these preference weights also ensure that the model matches total health spending and the fraction of individuals with health insurance per age group.

We allow for 4 permanent skill types $\vartheta$ is skill type. The permanent skill types are defined as average individual wages per wage quartile. The efficiency unit of labor, i.e., labor productivity, evolves over the lifecycle according to

$$e_j(\vartheta, h_j, \varepsilon^n) = (\bar{\varepsilon}_{j,\vartheta})^\chi \times \left(\exp\left(\frac{h_j - \bar{h}_{j,\vartheta}}{\bar{h}_{j,\vartheta}}\right)\right)^{1-\chi} \times \varepsilon^n \text{ for } j = \{1, \ldots, J_1\}, \quad (16)$$

where $\bar{\varepsilon}_{j,\vartheta}$ is the average productivity of labor of the $(j, \vartheta)$ types. We estimate $\bar{\varepsilon}_{j,\vartheta}$ from MEPS data using average wages which results in hump-shaped lifecycle earnings profiles. In addition, labor productivity can be influenced by health. The idiosyncratic health effect on labor productivity is measured as deviation from the average health $\bar{h}_{j,\vartheta}$ per skill and age group. In order to avoid negative numbers we use the exponent function. Parameter $\chi = 0.85$ measures the relative weight of the average productivity vs. the individual health effect. Finally, the idiosyncratic labor productivity shock $\varepsilon^n$ is based on Storesletten, Telmer and Yaron (2004). We discretize this process into a five state Markov process following Tauchen (1986).

4.3 Health Capital

We use the health index Short-Form 12 Version 2 ($SF-12v2$) in MEPS data to measure health capital. The $SF-12v2$ includes twelve health measures of physical and mental health. It is widely used to assess health improvements after medical treatments in hospitals. The $SF-12v2$ has continuous value and varies between between 0 (worst) and 100 (best).

---

6See Ware, Kosinski and Keller (1996) for further details about this health index.
We first define a space for health capital in the model with a minimum health capital level of \( h^\text{min}_m \) and a maximum health capital level of \( h^\text{max}_m \). We set the maximum health capital level \( h^\text{max}_m \) and map the health index from MEPS data to the health capital space in the model. Note that, we normalize health capital and health production parameters according to the maximum health level. The lower bound of the health grid \( h^\text{min}_m \) is calibrated.

We classify individual health status into four groups by age-cohort and health capital quartile (i.e., group 1 has health capital in the 25\(^{th}\) percentile whereas group 4 has health capital in the top quartile). We assume that individuals in group 1 are in the best health status, so that there is negligibly small or no health shock. Meanwhile, individuals in the other health groups experience negative health shocks. Group 2 experiences a “small” health shock, group 3 experiences a “moderate” health shock, and group 4 suffers from a “large” health shock. The transition probability matrix of health shocks \( \Pi^h \) is calculated by counting how many individuals move across health groups between two consecutive years in MEPS data where we also adjust for period length.

In order to measure the magnitudes of health shocks, we compute the average health capital of group, \( \bar{h}_{i,j,d} \) with \( i = \{1, 2, 3, 4\} \). The average health capital per age group is denoted \( \{ \bar{h}_{1,j,d}, \bar{h}_{2,j,d}, \bar{h}_{3,j,d}, \bar{h}_{4,j,d} \} \). We measure the shock magnitude in terms of relative distance from an average health state of each group to the average health state of group 1, \( \left( \frac{\bar{h}_{1,j,d}-\bar{h}_{i,j,d}}{\bar{h}_{1,j,d}} \right) \). The vector of shock magnitude in percentage deviation is defined as \( \varepsilon^h_{\%} = \left\{ 0, \frac{\bar{h}_{2,j,d}-\bar{h}_{1,j,d}}{\bar{h}_{1,j,d}}, \frac{\bar{h}_{3,j,d}-\bar{h}_{1,j,d}}{\bar{h}_{1,j,d}}, \frac{\bar{h}_{4,j,d}-\bar{h}_{1,j,d}}{\bar{h}_{1,j,d}} \right\} \). This vector is scaled by the maximum health capital level in the model \( h^\text{max}_m \) and used as the shock levels in the model.

The natural rate of health depreciation \( \delta^h_{j} \) per age group is calculated by focusing on individuals with group insurance and zero health spending in any given year. We then postulate that such individuals did not incur a negative health shock in this period as they could easily afford to buy medical services \( m \) to replenish their health due to their insurance status. This allows us to back out the depreciation rate from expression (9).

To the best of our knowledge, there are no suitable estimates for health production processes in equation (9), especially within macro modeling frameworks. A recent empirical contribution by Galama et al. (2012) finds weak evidence for decreasing returns to scale which implies \( \xi < 0 \). In our paper we calibrate \( \xi \) and \( \phi_j \) together to match aggregate health expenditures and the medical expenditure profile over age (see Figure 1). We assume a grid of 15 health states for our calibration in order to reduce the computational burden.

4.4 Health Insurance

**Group Insurance Offers.** MEPS data contain information about whether individuals have received a group health insurance offer from their employer i.e., offer shock \( \varepsilon^{\text{GHI}} \). The transition matrix \( \Pi^h \) with elements \( \Pr \left( \varepsilon^G_{j+1} = 1 | \varepsilon^G_{j}, \vartheta \right) \) depends on the permanent skill type \( \vartheta \).

\( ^7 \)We use OFFER31X, OFFER42X, and OFFER53X where the numbers 31, 42, and 53 refer to the interview round within the year (individuals are interviewed five times in two years). We assume that an individual was offered GHI when either one of the three variables indicates so.
We then count how many individuals with a GHI offer in year \( j \) are still offered group insurance in \( j + 1 \). We smooth the transition probabilities and adjust for the five-year period length.

**Insurance Premiums and Coinsurance Rates.** Insurance companies set premiums according to a person’s age and health status. Premiums \( \text{prem}^{\text{HII}}(j,h) \) will adjust to clear expression (11). Age and health dependent markup profits \( \omega_{j,h}^{\text{HII}} \) are calibrated to match the HI take-up rate by age group. Similarly, \( \text{prem}^{\text{GHI}} \) adjusts to clear expression (12) and the markup profit \( \omega^{\text{GHI}} \) is calibrated to match the insurance take-up rate of GHI. The coinsurance rate is defined as the fraction of out-of-pocket health expenditures over total health expenditures. Coinsurance rates therefore include deductibles and copayments. We use MEPS data to estimate coinsurance rates of \( \gamma_{\text{HII}}, \gamma_{\text{GHI}}, \gamma_{\text{MAid}} \), and \( \gamma_{\text{Mcare}} \) for individual, group, Medicaid and Medicare insurance, respectively.

**Price of Medical Services.** The base price of medical services \( p_m \) is endogenous as we model the production of medical services via expression (8). According to Shatto and Clemens (2011) we know that prices paid by Medicare and Medicaid are close to 70 percent of the prices paid by private health insurance who themselves pay lower prices than the uninsured due to their market power vis-a-vis health care providers (see Phelps (2003)). Various studies have found that uninsured individuals pay an average markup of 60 percent or more for prescription drugs as well as hospital services (see Playing Fair, State Action to Lower Prescription Drug Prices (2000), Brown (2006), Anderson (2007), Gruber and Rodriguez (2007)). Based on this information we pick the following markup factors for the five insurance types in the model:

\[
[p_{\text{noIns}}^m, p_{\text{HII}}^m, p_{\text{GHI}}^m, p_{\text{Maid}}^m, p_{\text{Mcare}}^m] = [0.70, 0.25, 0.10, 0.0, -0.10] \times p_m.
\]

When the experiments are run, this relative pricing structure is held constant so that Medicaid and Medicare remain the programs that pay the lowest prices for medical services. Thus, providers are assumed to not being able to renegotiate reimbursement rates.

**4.5 Fiscal Policy**

**Taxes.** The consumption tax rate, \( \tau_C \), is set to 5 percent. We follow Guner, Lopez-Daneri and Ventura (2016) and choose \( a_1 = 0.053 \) as the progressivity level in the benchmark model. We calibrate the tax level parameter to match the relative size of the government budget so that \( a_0 = 1.095 \).

**Social Security.** In the model, Social Security benefit payments are defined as a function of average labor income by skill type: \( t^{\text{Soc}}(\vartheta) = \Psi(\vartheta) \times w \times L(\vartheta) \), where \( \Psi(\vartheta) \) is a scaling vector that determines the total size of pension payments as a function of the average wage income by skill type. Total pension payments amount to 4.1 percent of GDP, similar to the number reported in the budget tables of the Office of Management and Budget (OMB) for 2008. The Social Security system is self-financed via a payroll tax of \( \tau^{SS} = 9.4 \) percent similar to Jeske and Kitao (2009). The Social Security payroll tax is collected on labor income up to a maximum of \$97,500.
**Medicare and Medicaid.** According to data from CMS (Keehan et al. (2011)) the share of total Medicaid spending on individuals older than 65 is about 36 percent. Adding this amount to the total size of Medicare results in public health insurance payments to the old of 4.16 percent of GDP. Given a coinsurance rate of $\gamma^R = 0.20$, the size of the combined Medicare/Medicaid program in the model is 3.1 percent of GDP. The premium for Medicare is 2.11 percent of per capita GDP as in Jeske and Kitao (2009). The Medicare tax $\tau^{Micare}$ is 2.9 percent and is not restricted by an upper limit (see Social Security Update 2007 (2007)).

According to MEPS data, 9.2 percent of working age individuals are on some form of public health insurance. We therefore set the Medicaid eligibility level in the model to 70 percent of the FPL (i.e., $FPL_{\text{Maid}} = 0.7 \times FPL$), which is the average state eligibility level (Kaiser (2013)) and calibrate the asset test level, $\bar{a}_{\text{Maid}}$, to match the Medicaid take-up rate. Setting the age dependent coinsurance rate for Medicaid $\gamma_j^{\text{Maid}}$ to MEPS levels, Medicaid for workers is 0.5 percent of GDP in the model which underestimates Medicaid spending of workers in MEPS.

Overall, the model results in total tax revenue of 21.8% of GDP and residual (unproductive) government consumption of 12 percent. The latter adjusts to clear the government budget constraint (13).

### 4.6 The Benchmark Model

Figures 1, 2 and 3 and Table 3 in the Appendix show that the benchmark model matches the relevant elements of the MEPS data quite well. The model closely tracks average medical expenditures by age group (Figure 1, Panel [1]) and reproduces the extremely right skewed distribution of health expenditures shown (Figure 1, Panel [2]). Overall, the model generates total health expenditures of 12 percent of GDP. In addition, the model matches the insurance take-up percentages of IHI, GHI and Medicaid by age group as shown in Figure 1, Panels [3], [4] and [5] respectively.

The model reproduces the hump-shaped patterns of asset holdings (Figure 2, Panel [1]). However, the lack of a formal bequest motive in the model generates a shift in asset holdings from retirees to the working age population. On the other hand, the model provides a close fit to the average household income over the lifecycle (Figure 2, Panel [2]). Retired individuals decrease their consumption faster than in the data which is a result of the low asset holdings of the elderly (Figure 2, Panel [3]). Finally, the model provides a close fit for the lifecycle pattern of labor supply (Figure 2, Panel [4]). Figure 3 compares the model income and wage distribution to data from MEPS. The model matches the lower and upper tails of the income distribution with around 12 percent individuals with income below 133 percent of the Medicaid threshold, $FPL_{\text{Maid}}$. Compare Remler and Glied (2001) and Aizer (2003) for additional discussions of Medicaid take-up rates.

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8Our model cannot match the NIPA number because it is calibrated to MEPS data which only accounts for about 65-70 percent of health care spending in the national accounts (see Sing et al. (2006) and Bernard et al. (2012)).

9All model experiments that expand the Medicaid program are percentage expansions based on the model threshold, $FPL_{\text{Maid}}$. Compare Remler and Glied (2001) and Aizer (2003) for additional discussions of Medicaid take-up rates.

10Overall Medicaid spending in MEPS, workers and retirees, accounts for about 0.95 to 1.02 percent of GDP according to Sing et al. (2006), Keehan et al. (2011) and Bernard et al. (2012).
eligibility level (MaidFPL). Finally, Table 3 compares first moments from the model to data moments from MEPS, CMS, and NIPA.

5 Results

We first characterize the optimal income tax system for the benchmark economy using a 2-parameter income tax function following Benabou (2002). We then analyze how the optimal level of progressivity changes after the introduction of the Affordable Care Act of 2010 which is a large scale reform that redistributes income from high income and healthy individuals to low income and sicker individuals. Finally, we analyze to what extent the particular parametric assumption about the income tax polynomial affects our results by using different parameterizations from the literature.

5.1 The Optimal Income Tax System

The Government Problem. In order to characterize the optimal level of progressivity in the tax function in this large-scale OLG model with uninsurable idiosyncratic risk and endogenous health spending we follow the Ramsey tradition and restrict the choice dimension of the government similar to Conesa, Kitao and Krueger (2009). We assume that the social welfare function—defined as the ex-ante lifetime utility of an individual born into the stationary equilibrium—depends on the two parameters of the income tax polynomial so that \( WF(a_0, a_1) = \int V(x_j=1|a_0, a_1) d\Lambda(x_j=1) \). The government’s objective is to choose the tax parameter values \( \{a_0, a_1\} \) in order to maximize the social welfare function taking the decision rules of consumers and firms as well as competitive equilibrium conditions into account. All other policy variables are kept unchanged.

We implement the maximization by searching over a grid of values for progressivity parameter \( a_1 \) while letting the scaling parameter \( a_0 \) adjust to keep the government budget balanced. The level of exogenous government consumption \( C_G \) remains identical to the benchmark government consumption level \( \overline{C_G} \). The tax maximization problem can be written as

\[
WF^* = \max_{\{a_0, a_1\}} \int WF(a_0, a_1)
\]

s.t.

\[
\sum_{j=1}^J \mu_j \int tax_j(a_0,a_1,x_j) d\Lambda(x_j) = \overline{C_G} + T^{SI}(a_0,a_1) + Medicaid(a_0,a_1) + Medicare(a_0,a_1)
\]

\[- \tau^C C(a_0,a_1) - Medicare Prem(a_0,a_1) - Medicare Tax(a_0,a_1),
\]

where the terms on the right hand side of the constraint are aggregates that depend on the tax parameters due to tax distortions and general equilibrium price effects.

The Optimal Progressivity of Income Taxes. Figure 4 presents the results of the tax optimization. We find that the optimal progressivity level \( a_1^* = 0.247 \) is higher than the U.S.
benchmark case of $a_1 = 0.053$. In Panel [1] of Figure 4 we compare the tax burdens of the U.S. Benchmark to the optimal tax system. Under the optimal tax system (red dotted line) low and lower-middle income households pay almost zero taxes, whereas higher-middle and high income households pay significantly more than under the benchmark case. Panel [2] presents the average tax rates per income group and Panel [3] displays the marginal tax rates. The optimal income tax includes a tax break for income earners below US$ 38,000 followed by a jump in the marginal tax rate to 25 percent and a steep increase thereafter to top marginal rates of over 40 percent and over 50 percent for income earners above US$ 100,000 and above US$ 200,000, respectively. The optimal income tax system is more progressive than the benchmark system. The tax burden is allocated mainly to the top of the income distribution.

The optimal tax system in our model is different from the optimal tax systems in previous studies that abstracts from health risk. For comparison, we plot the optimal tax systems in Conesa and Krueger (2006) and Heathcote, Storesletten and Violante (2016). Heathcote, Storesletten and Violante (2016) find an optimal progressivity parameter of $a_1^* = 0.084$ and a scaling parameter of $a_0 = 0.233$. Note that Heathcote, Storesletten and Violante (2016) use a different model which does not explicitly track Social Security, Medicare and Medicaid. They also include government consumption ($C_G$) in household preferences. Conesa and Krueger (2006) use a different parametric specification of the tax function. Their tax function has three parameters. Their optimal tax is a proportional tax of 17.2 percent with a fixed deduction of about US$ 9,400. It is important to note that earnings risk is is the main driver behind household heterogeneity. Health risk and institutional details of the U.S. health insurance system are not in play in these two studies. Retirees are not exposed to health or income risk after retirement.

Our result is in line with the more recent literature on income taxation which also finds much higher marginal tax rates in the range of 75 – 90 percent for top income earners than previous studies (e.g., Diamond and Saez (2011), Badel and Huggett (2014) and Kindermann and Krueger (2015)). In particular, Kindermann and Krueger (2015) show that very high marginal tax rates for the top one percent are primarily driven by the social insurance benefits that these high taxes imply. In their model—in order to match the very high concentration of labor earnings and wealth in the data—they require that households have the opportunity to work for very high wages with very low probability. Then, as a result of precautionary motives, the labor supply of these households is not strongly affected by high marginal taxes. The intuition is that during the periods of high labor productivity households work hard and earn the majority of their lifetime income. There is a similar mechanism in our framework where households are exposed to health risks throughout the lifecycle. Precautionary motives are relatively strong in our setting because households face severe health shocks at the end of their life as shown in De Nardi, French and Jones (2010). Labor supply and savings of high skill households are not strongly affected by high marginal tax rates. From the social welfare perspective it is optimal to impose very high rates on high income households so that the government can provide social insurance against idiosyncratic earnings- and health risk through progressive taxes.
In panel [4], we present the income distribution of the benchmark case and the optimal tax case. The fraction of the poor households with income below US$ 20,000 decreases in the optimal tax system. Income inequality decreases after introducing the optimal tax system. The Gini coefficient for after tax income decreases from 0.38 to 0.31. The increase in income equality is due to the more progressive income tax system as well as general equilibrium effects that reduce the number of top income earners in the population.

**Tax Progressivity.** In order to obtain a better understanding for how the level of tax progressivity changes under different tax systems we follow Suits (1977) and construct Lorenz-type tax contribution curves and the Suits index. The Suits index is an aggregate measure of tax progressivity which is widely used in the empirical public finance and tax policy literature. However, it is rarely used in the macro/public finance literature. Intuitively, the Suits index measures concentration of aggregate tax contributions by income group. Figure 6 illustrates the tax-income Lorenz curve and its relationship to the Suits index. These Lorenz-type curves for tax contributions of the lowest to highest income group provide an aggregate measure of tax progressivity and the relative contributions by income group. The Suits index is in essence a Gini coefficient for tax contribution inequality. It varies from +1 (most progressive) where the entire tax burden is allocated to members of the highest income bracket, through 0 for a proportional tax, and to −1 (most regressive) where the entire tax burden is allocated to members of the lowest income bracket.

Panel [1] in Figure 7 presents the standard Lorenz curve for gross income. Panel [2] displays the Suits curve for income tax contributions by income group. Panel [3] presents the Suits curve for the total tax contribution (progressive income tax and other taxes) by income group.

As seen in panel [2], the Suits curve for the income tax contribution in the optimal tax system is flatter at the bottom and steeper at the top compared to the benchmark tax system. This indicates that there are significant changes in the allocation of tax burdens across income groups. The Suits index is 0.17 in the benchmark economy. The optimal tax system is very progressive with a Suits index around 0.53.

**Macroeconomic Aggregates.** Macroeconomic and welfare effects are summarized in Table 4. In the optimal tax system the government cuts taxes for households with incomes below US$ 60,000 per year and imposes higher taxes on households with incomes higher than that. The tax increases distort individuals’ incentives to save and work. Capital in the non-medical and medical sectors decreases. Weekly hours worked decrease from 29.4 hours to 29.0 hours. These distortions subsequently lead to efficiency losses and lower GDP by about 6 percent.

**Welfare.** The optimal tax system improves risk sharing across agents and redistributes income toward low income households which can result in welfare gains if distortions of the tax system remain small enough. In order to assess the variation of welfare effects across the income distribution, we compute compensating consumption by permanent income (skill) types. As expected, we find that the welfare effects vary significantly across the four permanent skill types. Workers with medium and high skill levels experience welfare losses, while low skill
workers experience welfare gains in the new steady state. The welfare gain for the lowest skill type can be large at up to 21 percent of lifetime consumption whereas welfare losses can amount to 33 percent for the highest income types. Overall, we observe a net welfare gain of 5.5 percent at the aggregate level when switching to the optimal income tax system. The positive welfare outcome indicates that the welfare gains resulting from better risk sharing and redistribution dominate the welfare losses caused by tax distortions.

5.2 Health Insurance and Tax Progressivity

The health insurance system provides a mechanism to insure against health risk and income risk as it redistributes income to low income and relatively sicker households. The design of the health insurance system has implications for the optimal tax progressivity. We next analyze how the introduction of the Affordable Care Act (hereafter, ACA) changes the optimal income tax system.

The ACA Reform. The ACA represents the most significant reform of the U.S. health care system since the introduction of Medicare in 1965. The key policy instruments embedded in the ACA are: (i) an insurance mandate enforced by penalties, (ii) the introduction of insurance exchanges with premium subsidies, (iii) a Medicaid expansion and (iv) new taxes on high income earners. As such the ACA provides a large redistribution program from healthy high income types to sicker low income types as shown in Jung and Tran (2016). In this section we analyze how the ACA changes the optimal progressivity level of the U.S. income tax system.

The following features of the ACA are added to the model. First, we introduce a penalty of 2.5 percent of taxable income on workers without health insurance which enters the budget constraint as

$$\text{penalty}_{j} = 1_{[\text{ins}_{j+1}=0]} \times 0.025 \times \tilde{y}_{j},$$

where $1_{[\text{ins}_{j}=0]}$ is an indicator variable equal to one if the household has no health insurance. Furthermore, we do not allow IHI companies to screen anymore. The price setting in GHI and IHI markets is now similar, except for the fact that IHI premiums are not tax deductible. Second, workers who are not offered insurance from their employers are eligible to buy health insurance through insurance exchanges at subsidized rates according to

$$\text{subsidy}_{j} = \begin{cases} 
\max \left(0, \text{prem}_{j}^{\text{IHI}} - 0.03\tilde{y}_{j}\right) & \text{if } 1.33 \text{ FPLMaid} \leq \tilde{y}_{j} < 1.5 \text{ FPLMaid}, \\
\max \left(0, \text{prem}_{j}^{\text{IHI}} - 0.04\tilde{y}_{j}\right) & \text{if } 1.5 \text{ FPLMaid} \leq \tilde{y}_{j} < 2.0 \text{ FPLMaid}, \\
\max \left(0, \text{prem}_{j}^{\text{IHI}} - 0.06\tilde{y}_{j}\right) & \text{if } 2.0 \text{ FPLMaid} \leq \tilde{y}_{j} < 2.5 \text{ FPLMaid}, \\
\max \left(0, \text{prem}_{j}^{\text{IHI}} - 0.08\tilde{y}_{j}\right) & \text{if } 2.5 \text{ FPLMaid} \leq \tilde{y}_{j} < 3.0 \text{ FPLMaid}, \\
\max \left(0, \text{prem}_{j}^{\text{IHI}} - 0.095\tilde{y}_{j}\right) & \text{if } 3.0 \text{ FPLMaid} \leq \tilde{y}_{j} < 4.0 \text{ FPLMaid}, 
\end{cases}$$

(18)

The subsidies ensure that the premiums that an individual pays at the health insurance exchange for IHI will not exceed a certain percentage of her taxable income $\tilde{y}_{j}$ at age $j$. Third, the ACA

\[\text{We do not model employer penalties.}\]
expands the Medicaid eligibility threshold to 133 percent of the FPL and removes the asset test. After the reform is implemented all individuals with incomes lower than 133 percent of the FPL will be enrolled in Medicaid. Finally, the reform is financed by increases in capital gains taxes for individuals with incomes higher than $200,000 per year (or $250,000 for families). In the model we use a flat income tax on individuals with incomes higher than $200,000. Summarizing, we can write the new household budget constraint with the ACA as

\[(1 + \tau^C) c_j + (1 + g) a_{j+1} + o^W (m_j) + 1_{[m_{j+1}=1]} \text{prem}^{\text{HII}} + 1_{[m_{j+1}=2]} \text{prem}^{\text{GHI}} = y_j + t^S - tax_j - 1_{[m_{j+1}=0]} \text{penalty}_j + 1_{[m_{j+1}=1]} \text{subsidy}_j - tax_j^{\text{ACA}}.\]

The Optimal Tax System. We next solve for a new steady state with the described features of the ACA as our new benchmark. We then use the new level of unproductive government consumption $C_G$ and solve the government maximization problem (17) with the ACA in place for the optimal tax progressivity rate $a^*_1$. We report the results of this exercise in Table 4, column [3] and Figure 5.

The optimal progressivity level is $a^*_1 = 0.24$ in the economy with the ACA insurance system. It is slightly lower than $a^*_1 = 0.247$ in the benchmark case prior to the ACA. Figure 5 compares the two optimal tax systems: one before ACA and one after ACA. As seen in panel [3], the optimal marginal tax schedule shifts left after introducing the ACA. This indicates that the fixed deduction is smaller and the marginal tax rates are larger for each income group which implies less progressivity overall as measured by the Suits index. Households with annual income around $35,000 would have to pay taxes in the ACA-case whereas before they were not taxed at all. The ACA provides a significant redistribution of wealth from healthy high income types to sicker low income types through subsidies and the expansion of Medicaid. The government factors in the redistribution that is already in place through the ACA when it optimizes the income tax code and the result is that the new optimal tax system is slightly less progressive than before with a slightly lower Suits index of 0.52.

5.3 Alternative Tax Function

In this section we analyze how robust our results are with respect to a different tax function specification.

Two Parameter Specification. We first relax the assumption that the tax payment has to be non-negative and use the original specification as in Benabou (2002)

\[\tilde{\tau}(\tilde{y}) = \left[\tilde{y} - a_0 \times \tilde{y}^{(1-a_1)}\right].\]

This specification allows for additional government transfers for poor households. We re-calibrate the model and solve again for the optimal tax progressivity where $a^*_0 = 1.687$ and $a^*_1 = 0.1666$. We again report marginal tax rates, average tax rates and tax payments by income group in Figure 8. The optimal marginal tax rates are negative for households with very low income. This implies that the poor households receive transfers from the government.
via the tax system itself. The tax payments become positive only when household incomes rise above US$ 5,000. The marginal tax rates are around 20 percent when household incomes reach US$ 30,000. Households with incomes above US$ 100,000 face marginal tax rates of over 35 percent.

The marginal tax rates are substantially lower when removing the restriction of non-negative tax contribution as the entire tax function shifts downward. The households at the bottom of the income distribution receive transfers, while the households at the top pay less in taxes in the new optimal tax system. This finding indicates that the government transfers to the low income households are important to pin down the optimal marginal tax rates for high income households in a general equilibrium setting.

**Three Parameter Specification.** We now consider a commonly used polynomial for progressive income taxation based on Gouveia and Strauss (1994)

\[
\tilde{\tau} (\tilde{y}) = a_0 \left[ \tilde{y} - (\tilde{y}^{-a_1} + a_2)^{-1/a_1} \right],
\]

where \( \tilde{y} \) is taxable income. This specification has three parameters and covers several special cases. For \( a_1 = -1 \), it is a constant tax independent of income \( \tilde{\tau} (\tilde{y}) = -a_0a_2 \). For \( a_1 \to 0 \), it is a purely proportional system. For \( a_1 > 0 \) it is a progressive tax system. Guner, Kaygusuz and Ventura (2014) estimate this three parameter specification using U.S. public use tax data and find it performs better than the two parameter specification.

In our benchmark calibration we use \( a_0 = 0.258 \), \( a_1 = 0.768 \) and \( a_2 = 0.031 \). The first two parameter values are from Gouveia and Strauss (1994), while the last parameter is calibrated to balance the government budget in the benchmark economy. We solve for an optimal taxation problem in which the government problem is to choose the tax parameter values \( \{a_0, a_1, a_2\} \) in order to maximize the social welfare function accounting for the optimal decisions of firms and households and competitive equilibrium conditions. Our results show that the parameter values for the optimal tax system are \( a_0^* = 0.517 \), \( a_1^* = 2.167 \). and \( a_2^* = 0.000108 \). Figure 9 presents the results for the three parameter specification of the tax polynomial.

Conesa and Krueger (2006) use the same tax polynomial and search for the optimal progressivity of the U.S. income tax code in a heterogeneous household model. The main difference between their model and ours is that we include health risk and a detailed representation of U.S. health insurance system. They find that households with income higher than US$ 9,400 pay the equivalent of a proportional tax of 17.2 percent. The optimal tax system in our setting is different. As shown in Figure 9, Panel [3] the optimal tax system starts from very low marginal tax rates on low income agents, but marginal tax rates increase sharply as household income rises. Households with income around US$ 40,000 face a similar marginal tax rate of around 17 percent. However, middle income households with income higher than US$ 50,000 face much higher marginal tax rates. Households with income over US$ 90,000 pay marginal tax rates above 40 percent.

The new optimal tax system under a 3–parameter specification is quite different from the optimal tax system with two parameters in the previous section. In particular, marginal tax
rates for low and middle income households are completely different. That is, the marginal tax rates for those households are higher in the three parameter specification. Interestingly, the marginal tax rates for households at the top of the income distribution are similar in both two optimal tax systems. Guner, Kaygusuz and Ventura (2014) provide estimates of different tax functions using micro data from the U.S. Internal Revenue Service. They argue that their estimates are ready to use for applied work in macroeconomics and public finance. Our result implies that the optimal progressive income tax system is sensitive to the specification of the tax polynomial.

Finally, we analyze the effects of the ACA reform on the optimal income tax system with three parameters. We present the effects in Figure 10. The introduction of the ACA results in similar effects as under the tax regime model with a 2–parameter polynomial. The optimal tax function is shifts to the left and the welfare maximizing progressivity level of the income tax code decreases. This finding is similar to our earlier results with the exception that the welfare gains measured in terms of compensating consumption are somewhat smaller.

6 Conclusion

In this paper we investigate the optimal level of progressivity in income taxation in a Bewley-Grossman model of health capital where individuals face uninsurable income and health risks over the lifecycle. In our setting health affects the labor market productivity of workers so that health serves as a consumption and as an investment good. Individuals subsequently smooth their consumption in the presence of idiosyncratic earnings shocks using a limited set of instruments. In addition to earnings shocks, individuals are also exposed to idiosyncratic health shocks. Individuals choose to invest in their health via purchases of medical services. The income and wealth distribution is a function of both stochastic, persistent, and exogenous earning risk and health risk and endogenous health capital accumulation.

We calibrate the benchmark model to match the U.S. economy in 2010. We then quantitatively characterize the optimal progressivity of the U.S. income tax system. We show that the optimal system is very progressive with much higher levels of progressivity than the U.S. benchmark income tax system. Our findings highlight that the progressive income tax system plays a key role in shaping the income distribution across households. Income inequality decreases under the optimal system as measured by after-tax income Gini coefficients. A fundamental tax reform that switches the current U.S. income tax system to a more progressive welfare maximizing system results in large welfare gains. However, this switch generates winners and losers in welfare terms. The poor and lower-middle income households gain because of lower taxes whereas high income earners suffer from higher taxes. Implementing such a reform is therefore politically problematic.

In addition, we quantify the optimal progressivity of the income tax code after the implementation of the ACA, a large scale health insurance reform that redistributes income from high income healthy types to low income sicker types. Our results indicate that the optimal
level of progressivity is affected by the interaction between income and health risks over the lifecycle as well as on the specific design of the health insurance system. Finally, we find that the parametric specification of the progressive tax function matters quantitatively for the design of the optimal progressive income tax system.

In this paper we only focus on the progressive income tax system. Broader tax instruments can be investigated in our framework. For example, a switch from a progressive income tax to a progressive consumption tax is an interesting case. Analyzing the optimal design of the whole tax and transfer system in this environment is another step forward. We leave these issues for future work. In addition, we leave bequest motives, health state dependence of survival and transition dynamics for future extensions.


7 Appendix

7.1 Appendix A: Recursive Equilibrium

Given transition probability matrices \( \{ \Pi^n_j \}_{j=1}^J \) and \( \{ \Pi^h_j \}_{j=1}^J \); survival probabilities \( \{ \pi_j \}_{j=1}^J \) and exogenous government policies \( \{ \text{tax} (x_j), \tau^C_j, \tau^{SS}_j, \bar{c}, \bar{y} \}_{j=1}^J \), a competitive equilibrium is a collection of sequences of distributions \( \{ \mu_j, \Lambda_j (x_j) \}_{j=1}^J \) of individual household decisions \( \{ c_j (x_j), n_j (x_j), a_{j+1} (x_j), m_j (x_j), \ln_j (x_j) \}_{j=1}^J \), aggregate stocks of physical capital and effective labor services \( \{ K, N, K_m, N_m \} \), and factor prices \( \{ w, q, R, p_m \} \) such that

(a) \( \{ c_j (x_j), n_j (x_j), a_{j+1} (x_j), m_j (x_j), \ln_j (x_j) \}_{j=1}^J \) solves the consumer problem (15),

(b) the firm first order conditions hold in both sectors

\[
\begin{align*}
w &= F_N (K, N) = p_m F_{m, N_m} (K_m, N_m), \\
q &= F_K (K, N) = p_m F_{m, K_m} (K_m, N_m), \\
R &= q + 1 - \delta,
\end{align*}
\]

(c) markets clear

\[
\begin{align*}
K + K_m &= \sum_{j=1}^J \mu_j \int (a (x_j)) d\Lambda (x_j) + \sum_{j=1}^J \int \tilde{\mu}_j a_j (x_j) d\Lambda (x_j), \\
N + N_m &= \sum_{j=1}^J \mu_j \int e_j (x_j) n_j (x_j) d\Lambda (x_j),
\end{align*}
\]

(d) the aggregate resource constraint holds

\[
G + (1 + g) S + \sum_{j=1}^J \mu_j \int (c (x_j) + p_m m (x_j)) d\Lambda (x_j) = Y + p_m Y_m + (1 - \delta) K,
\]

(e) the government programs clear

\[
\begin{align*}
\sum_{j=J+1}^J \mu_j \int t^{SS}_j (x_j) d\Lambda (x_j) &= \sum_{j=1}^{J_1} \mu_j \int t^\tau (x_j) d\Lambda (x_j), \\
M^G + \sum_{j=1}^J \mu_j \int t^{SI}_j (x_j) d\Lambda (x_j) + G &= \sum_{j=1}^J \mu_j \int [ \tau^C c (x_j) + \text{tax} (x_j) ] d\Lambda (x_j), \quad (19)
\end{align*}
\]
(f) the accidental bequest redistribution program clears
\[
\sum_{j=1}^{J_1} \mu_j \int t_{j}^{\text{Beq}} (x_j) \, d\Lambda (x_j) = \sum_{j=1}^{J} \int \tilde{\mu}_j a_j (x_j) \, d\Lambda (x_j),
\]

(g) the insurance system is self-financed so that insurance payouts over all participants equal premium contributions and/or ear marked tax collections and
\[12\]

(h) the distribution is stationary \( \mu_{j+1}, \Lambda (x_{j+1}) = T_{\mu,\Lambda} (\mu_j, \Lambda (x_j)) \) where \( T_{\mu,\Lambda} \) is a one period transition operator on the distribution.

\[12\] We discuss the specifics of the insurance system in the following sections.
7.2 Appendix B: Calibration Tables

<table>
<thead>
<tr>
<th>Parameters:</th>
<th>Explanation/Source:</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Periods working</td>
<td>$J_1 = 9$</td>
</tr>
<tr>
<td>- Periods retired</td>
<td>$J_2 = 6$</td>
</tr>
<tr>
<td>- Population growth rate</td>
<td>$n = 1.2%$</td>
</tr>
<tr>
<td>- Years modeled</td>
<td>$years = 75$</td>
</tr>
<tr>
<td>- Total factor productivity</td>
<td>$A = 1$</td>
</tr>
<tr>
<td>- Growth rate</td>
<td>$g = 2%$</td>
</tr>
<tr>
<td>- Capital share in production</td>
<td>$\alpha = 0.33$</td>
</tr>
<tr>
<td>- Capital in medical services prod.</td>
<td>$\alpha_m = 0.26$</td>
</tr>
<tr>
<td>- Capital depreciation</td>
<td>$\delta = 10%$</td>
</tr>
<tr>
<td>- Health depreciation</td>
<td>$\delta_{h,j} = [0.6% - 2.13%]$</td>
</tr>
<tr>
<td>- Survival probabilities</td>
<td>$\pi_j$</td>
</tr>
<tr>
<td>- Health Shocks</td>
<td>Technical Appendix</td>
</tr>
<tr>
<td>- Health transition prob.</td>
<td>Technical Appendix</td>
</tr>
<tr>
<td>- Productivity shocks</td>
<td>see Section 2</td>
</tr>
<tr>
<td>- Productivity transition prob.</td>
<td>Technical Appendix</td>
</tr>
<tr>
<td>- Group ins. transition prob.</td>
<td>Technical Appendix</td>
</tr>
<tr>
<td>- Price for medical care for uninsured</td>
<td>$\nu_{\text{noIns}} = 0.7$</td>
</tr>
<tr>
<td>- M price markup for IHI insured</td>
<td>$\nu_{\text{IHI}} = 0.25$</td>
</tr>
<tr>
<td>- M price markup for GHI insured</td>
<td>$\nu_{\text{GHI}} = 0.1$</td>
</tr>
<tr>
<td>- M price markup for Medicaid</td>
<td>$\nu_{\text{Maid}} = 0.0$</td>
</tr>
<tr>
<td>- M price markup for Medicare</td>
<td>$\nu_{\text{Mcare}} = -0.1$</td>
</tr>
<tr>
<td>- Coinsurance rate: IHI in %</td>
<td>$\gamma_{IHI} \in [22, 46, 48, 49, 50, 53, 52, 50]$</td>
</tr>
<tr>
<td>- Coinsurance rate: GHI in %</td>
<td>$\gamma_{GHI} \in [33, 33, 33, 34, 36, 36, 45, 50]$</td>
</tr>
<tr>
<td>- Medicare premiums/GDP</td>
<td>2.11%</td>
</tr>
<tr>
<td>- Medicaid coinsurance rate in %</td>
<td>$\gamma_{\text{Maid}} \in [11, 14, 17, 16, 17, 18, 20, 22]$</td>
</tr>
<tr>
<td>- Public coinsurance rate retired in %</td>
<td>$\gamma^R = 20$</td>
</tr>
<tr>
<td>- Payroll tax Social Security:</td>
<td>$\tau^{\text{Soc}} = 9.4%$</td>
</tr>
<tr>
<td>- Consumption tax:</td>
<td>$\tau^C = 5.0%$</td>
</tr>
<tr>
<td>- Payroll tax Medicare:</td>
<td>$\tau^M = 2.9%$</td>
</tr>
</tbody>
</table>

Table 1: External Parameters
These parameters are based on our own estimates from MEPS and CMS data as well as other studies.
**Parameters:**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Explanation/Source:</th>
<th>Nr.M.</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Relative risk aversion</td>
<td>$\sigma = 3.0$</td>
<td>1</td>
</tr>
<tr>
<td>- Preference on consumption vs. leisure:</td>
<td>$\eta = 0.43$</td>
<td>1</td>
</tr>
<tr>
<td>- Preference on $c$ and $l$ vs. health</td>
<td>$\kappa = 0.75$</td>
<td>1</td>
</tr>
<tr>
<td>- Discount factor</td>
<td>$\beta = 1.0$</td>
<td>1</td>
</tr>
<tr>
<td>- GHI markup profits</td>
<td>$\omega_{GHI} = 0$</td>
<td>1</td>
</tr>
<tr>
<td>- IHI markup profits</td>
<td>$\omega_{j,h} \in [0.6 - 1.5]$</td>
<td>8</td>
</tr>
<tr>
<td>- Health production productivity</td>
<td>$\phi_j \in [0.2 - 0.45]$</td>
<td>15</td>
</tr>
<tr>
<td>- TFP in medical production</td>
<td>$A_m = 0.4$</td>
<td>1</td>
</tr>
<tr>
<td>- Production parameter of health</td>
<td>$\xi = 0.26$</td>
<td>1</td>
</tr>
<tr>
<td>- effective labor services production</td>
<td>$\chi = 0.85$</td>
<td>1</td>
</tr>
<tr>
<td>- Health productivity</td>
<td>$\theta = 1.0$</td>
<td>1</td>
</tr>
<tr>
<td>- Pension replacement rate</td>
<td>$\Psi = 40%$</td>
<td>1</td>
</tr>
<tr>
<td>- Fixed time cost of labor</td>
<td>$l_j \in [0.0 - 0.7]$</td>
<td>1</td>
</tr>
<tr>
<td>- Minimum health state</td>
<td>$h_{min} = 0.01$</td>
<td>1</td>
</tr>
<tr>
<td>- Asset test level</td>
<td>$\bar{a}_{Maid} = $150,000</td>
<td>1</td>
</tr>
<tr>
<td>-Total number of internal parameters:</td>
<td></td>
<td>44</td>
</tr>
</tbody>
</table>

**Table 2: Internal Parameters**

We choose these parameters in order to match a set of target moments in the data.

<table>
<thead>
<tr>
<th>Moments</th>
<th>Model</th>
<th>Data</th>
<th>Source</th>
<th>Nr.M.</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Medical expenses HH income</td>
<td>17.6%</td>
<td>17.07%</td>
<td>CMS communication</td>
<td>1</td>
</tr>
<tr>
<td>- Workers IHI</td>
<td>5.6%</td>
<td>7.2%</td>
<td>MEPS 1999/2009</td>
<td>1</td>
</tr>
<tr>
<td>- Workers GHI</td>
<td>61.1%</td>
<td>62.2%</td>
<td>MEPS 1999/2009</td>
<td>1</td>
</tr>
<tr>
<td>- Workers Medicaid</td>
<td>9.6%</td>
<td>9.2%</td>
<td>MEPS 1999/2009</td>
<td>1</td>
</tr>
<tr>
<td>- Capital output ratio: $K/Y$</td>
<td>2.7</td>
<td>2.6 - 3</td>
<td>NIPA</td>
<td>1</td>
</tr>
<tr>
<td>- Interest rate: $R$</td>
<td>4.2%</td>
<td>4%</td>
<td>NIPA</td>
<td>1</td>
</tr>
<tr>
<td>- Size of Social Security/Y</td>
<td>5.9%</td>
<td>5%</td>
<td>OMB 2008</td>
<td>1</td>
</tr>
<tr>
<td>- Size of Medicare/Y</td>
<td>3.1%</td>
<td>2.5 - 3.1%</td>
<td>U.S. Department of Health (2007)</td>
<td>1</td>
</tr>
<tr>
<td>- Medical spend. profile</td>
<td></td>
<td></td>
<td>MEPS 1999/2009</td>
<td>15</td>
</tr>
<tr>
<td>- IHI insurance take-up profile</td>
<td></td>
<td></td>
<td>MEPS 1999/2009</td>
<td>7</td>
</tr>
<tr>
<td>- Medicaid insurance take-up profile</td>
<td></td>
<td></td>
<td>MEPS 1999/2009</td>
<td>7</td>
</tr>
<tr>
<td>- Average labor hours</td>
<td></td>
<td></td>
<td>PSID 1984-2007</td>
<td>7</td>
</tr>
<tr>
<td>Total number of moments</td>
<td></td>
<td></td>
<td></td>
<td>44</td>
</tr>
</tbody>
</table>

**Table 3: Matched Data Moments**

We choose internal parameters so that model generated data matches data from MEPS, CMS, and NIPA.
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Output ($GDP$)</td>
<td>100</td>
<td>94.06</td>
<td>92.41</td>
</tr>
<tr>
<td>Capital ($K_e$)</td>
<td>100</td>
<td>93.26</td>
<td>91.19</td>
</tr>
<tr>
<td>Capital ($K_m$)</td>
<td>100</td>
<td>99.30</td>
<td>101.17</td>
</tr>
<tr>
<td>Weekly hours worked</td>
<td>29.40</td>
<td>29.00</td>
<td>28.20</td>
</tr>
<tr>
<td>Non- Med. Consumption ($C$)</td>
<td>100</td>
<td>92.75</td>
<td>89.78</td>
</tr>
<tr>
<td>Med. consumption ($M$)</td>
<td>100</td>
<td>99.41</td>
<td>101.23</td>
</tr>
<tr>
<td>Med. spending ($p_m M$)</td>
<td>100</td>
<td>100.46</td>
<td>96.79</td>
</tr>
<tr>
<td>Workers insured (%)</td>
<td>78.59</td>
<td>75.51</td>
<td>99.61</td>
</tr>
<tr>
<td>Medicaid (%)</td>
<td>9.56</td>
<td>6.18</td>
<td>10.01</td>
</tr>
<tr>
<td>Interest rate ($r$ in %)</td>
<td>5.07</td>
<td>5.08</td>
<td>5.08</td>
</tr>
<tr>
<td>Wage rate ($w$)</td>
<td>100.00</td>
<td>99.95</td>
<td>99.97</td>
</tr>
<tr>
<td>Gini (Total income)</td>
<td>0.44</td>
<td>0.41</td>
<td>0.42</td>
</tr>
<tr>
<td>Gini (Net income)</td>
<td>0.38</td>
<td>0.31</td>
<td>0.30</td>
</tr>
<tr>
<td>Suits index (Income tax)</td>
<td>0.17</td>
<td>0.53</td>
<td>0.52</td>
</tr>
<tr>
<td>Welfare (CEV):</td>
<td>0</td>
<td>+5.54</td>
<td>+3.14</td>
</tr>
<tr>
<td>• Income Group 1 (Low)</td>
<td>0</td>
<td>+21.10</td>
<td>+22.37</td>
</tr>
<tr>
<td>• Income Group 2</td>
<td>0</td>
<td>+12.10</td>
<td>+8.87</td>
</tr>
<tr>
<td>• Income Group 3</td>
<td>0</td>
<td>−9.71</td>
<td>−13.92</td>
</tr>
<tr>
<td>• Income Group 4 (High)</td>
<td>0</td>
<td>−33.10</td>
<td>−36.54</td>
</tr>
</tbody>
</table>

Table 4: Macroeconomic and Welfare Effects When Switching from the Benchmark System to the Optimal Tax Systems

This table presents steady state results comparing the benchmark economy to the equilibrium outcome with optimized income taxes without the ACA (column [2]) and with the ACA (column [3]). Data in rows marked with the % symbol are either fractions in percent or tax rates in percent. The other rows are normalized with values of the benchmark case. Each column presents steady-state results. CEV values are reported as percentage changes in terms of lifetime consumption of a newborn individual with respect to consumption levels in the benchmark.
7.3 Appendix C: Figures

Figure 1: **Health Expenditure and Insurance Take-up**
Model vs. data from MEPS 2000-2009.
Figure 2: Moment Matching using PSID 1984-2007 and CPS 1999-2009
Blue lines are model generated data moments and black dotted lines are PSID data in Panel 1 and 2 and CPS data in Panel 3.
Figure 3: **Moment Matching using MEPS 2000-2009**
Blue dots are model generated data moments and green dots lines are from PSID data.
Figure 4: The Optimal Income Taxes in the Benchmark Pre-ACA Economy
Progressive income taxes of the pre-ACA Benchmark case are based on Guner, Lopez-Daneri and Ventura (2016) and use the tax polynomial introduced in Benabou (2002). The Conesa and Krueger (2006) case is based on a model without health shocks and health insurance and uses a tax polynomial based on Gouveia and Strauss (1994).
Figure 5: The ACA and Optimal Income Tax System
Progressive income taxes of the pre-ACA Benchmark case are based on Guner, Lopez-Daneri and Ventura (2016) and use the tax polynomial introduced in Benabou (2002). The blue-circle line is the optimal tax without the ACA and the purple-triangle line is the optimal tax with the ACA. The Conesa and Krueger (2006) case is based on a model without health shocks and health insurance and uses a tax polynomial based on Gouveia and Strauss (1994).
Figure 6: Income Tax Lorenz Curves and Suits Index

The Tax Lorenz-type curve and Suits index measure the degree of disproportionality between pretax income and tax contributions by means of a relative concentration curve. The Suits index is essentially a Gini coefficient for tax contributions by income group. It varies from +1 (most progressive) where the entire tax burden is allocated to households of the highest income bracket, through 0 for a proportional tax, and to −1 (most regressive) where the entire tax burden is allocated to households of the lowest income bracket.
Figure 7: **Income and Income Tax Lorenz Curves**
Panel [1] presents Lorenz curves of taxable income (pre-ACA Benchmark), Panel [2] presents Suits curves of progressive income taxes based on *Suits* (1977) and Panel [3] presents Suits curves of total taxes, that is consumption taxes, progressive income taxes, and payroll taxes for social security and Medicare. For the ACA case total taxes also include a new tax on investment income of high income earners and penalties for being uninsured. Panel [4-6] present the cases with the ACA.

Progressive income taxes of the pre-ACA Benchmark case are based on *Guner, Lopez-Daneri and Ventura* (2016) and use the tax polynomial introduced in *Benabou* (2002). The ACA case uses the same tax structure as the pre-ACA Benchmark case.
Progressive income taxes of the Benchmark case are based on the original form in Benabou (2002) and Guner, Lopez-Daneri and Ventura (2016). We remove the restriction of non-negative income taxes. That, the government now can transfer to the low income households via negative taxes. The Conesa and Krueger (2006) case is based on a model without health shocks and health insurance and uses a tax polynomial based on Gouveia and Strauss (1994).
Figure 9: The Optimal Income Taxes Based on the Three Parameter Polynomial in Gouveia and Strauss (1994)

Progressive income taxes of the benchmark case are based on the tax polynomial introduced in Gouveia and Strauss (1994). The Conesa and Krueger (2006) case is based on a model without health shocks and health insurance and uses a tax polynomial based on Gouveia and Strauss (1994). The red dotted line is the optimal taxes.
Figure 10: The ACA and the Optimal Income Tax System Based on Gouveia and Strauss (1994)

The progressive income taxes are based on Gouveia and Strauss (1994). The red dotted line is the optimal tax without the ACA and the green dotted line is the optimal tax with the ACA. The Conesa and Krueger (2006) case is based on a model without health shocks and health insurance and uses a tax polynomial based on Gouveia and Strauss (1994)