Essays on Taxation

by

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Author's Declaration

I hereby declare that I am the sole author of the first two chapters of this thesis and I am the co-author of the third chapter with Associate Professor Cagri Kumru. Except where otherwise indicated, this thesis is an original work.

I understand that my thesis may be made electronically available to the public.

Yurui Zhang

May 31, 2022

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Abstract

There are three chapters in this thesis.

The first chapter studies the impact of different tax reforms of property tax and income tax on equilibrium house prices, rents, homeownership, and social welfare. Firstly, we examine the implication of the change in the proportional property tax rate. Our results show that increasing the proportional property tax rate decreases the homeownership rate and generates welfare losses. Secondly, we replace the proportional property tax with a progressive property tax system. We find that a more progressive property tax system generates a higher homeownership rate and more welfare gains. Thirdly, as we increase the progressivity of the income tax system, the low-income households have more after-tax income so that they have more incentive to purchase houses. Yet, the effect is limited. Again, we find that a more progressive income tax system generates higher welfare gains. In a nutshell, higher progressivity on income and property tax help induce the renters to become homeowners and improve the social welfare.

The second chapter studies the implications of an increase in consumption tax rates and the introduction of a progressive consumption tax system on economic aggregates, social welfare, and inequalities. We use a large-scale overlapping generation model with and without endogenous human capital accumulation. Our results show that when the consumption tax rate increases, the capital stock, the labour supply, and the output increase. In addition, the wealth inequality is mitigated. The presence of human capital accumulation does not change the direction of results. If the consumption tax rate is too high, the welfare loss is observed in both model settings. We show that switching to a progressive consumption tax system generates welfare gains in both models.

The third chapter analyses the optimal tax combination using a model that incorporates differential mortality and human capital accumulation. We calculate the optimal combinations of the capital income tax, consumption tax, and progressive labour income tax rates for the Chinese economy under four different model settings: standard life-cycle model without human capital accumulation (NHC), NHC model with differential mortality (NHC+DM), the life-cycle model with human capital accumulation (HC), HC model with differential mortality (HC+DM). Our results of implementing the optimal capital income tax rates in the Chinese economy are 8.1%, 7.9%, 2.6%, and 15.4%, respectively. The optimal labour income tax includes a 41.6% marginal tax rate with 98,010 yuan fixed deduction, a 21.0% marginal tax rate with 97,253 yuan deduction, a 3.1% marginal tax rate with 96,225 yuan deduction, and an 18.5% marginal tax rate with 97,535 yuan deduction, respectively. In a nutshell, we find that the optimal tax bundles under each model are different for China. It would be better to incorporate both human capital accumulation and differential mortality as a more comprehensive model for optimal taxation analysis in China.

Keywords: tax progressivity, property taxation, income taxation, consumption taxation, labour productivity, endogenous human capital accumulation, wealth inequality, differential mortality, optimal taxation

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List of Abbreviations

CBO	Congressional Budget Office.
CEV	Consumer Equivalent Variation.
CHIP	Chinese Household Income Project.
DM	Differential mortality.
GDP	Gross Domestic Production.
HC/HCA	Human capital accumulation.
NBSC	National Bureau of Statistics of China.
NHC/non HC	Non human capital accumulation.
OECD	The Organisation for Economic Co-operation and Development.
OLG	Overlapping Generations.
PSID	Panel Study of Income Dynamics.
TPC	Tax Policy Center.
USCB	U.S. Census Bureau.
WB	World Bank.

Chapter 1

Property Taxation and Tax Progressivity in the Housing Market

1.1 Introduction

Wealth taxation has gained much attention around the world due to the large wealth inequality. For instance, in the U.S., the wealth Gini coefficient is 0.85 while the income Gini coefficient is 0.39 (see Suisse (2019) and OECD (2021)). It is clear that the wealth inequality is much more severe than the income inequality in the U.S..[1] To reduce the wealth inequality, policymakers need to tax the wealthier individuals relatively more and subsidize others. OECD (2016) reports that 37.07% of U.S. households' wealth is contributed by the housing sector (see Figure 1.1).[2] In the same report, OECD (2016) also shows that low income households are struggling with owning a house: there is a huge diversified distribution among homeowners with respect to their income. In the U.S., 89.7% of upper income quintile households are homeowners while only 36.9% of bottom income quintile households are homeowners (see Figure 1.2). For the past two decades, the real housing prices has doubled during 1986 and 2021, while the nominal housing prices has almost increased four times during the same period, as OECD (2022a) reported. With such increasing prices, households have higher down payment to pay, which makes the

[1] Saez and Zucman (2016) show that in terms of wealth share, the top 0.1% wealth holders accumulate more than 20% of the total wealth. Top 1% wealth holders share almost 40% of the total wealth, while the bottom 90% households hold less than a quarter of all wealth. On one hand, the bottom 90% wealth holders obtain twice as their wealth share. On the other hand, the top 1% wealth holders collects half share of income as their wealth shares. Obviously, the share of wealth held by the wealthiest households substantially exceeds the share of income received by the highest-income households.

[2] An estimation given by Saez and Zucman (2016) shows a willingness to pay for either housing properties or shelter service is almost 100% of the households' income.

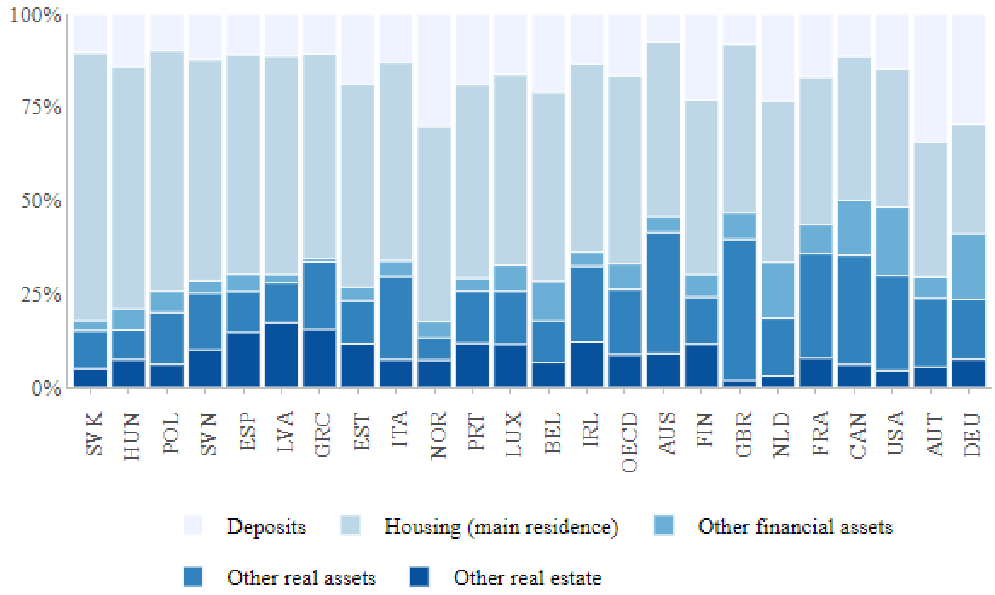

Figure 1.1: Asset decomposition of households' portfolio, % of total assets. Source: OECD (2016)

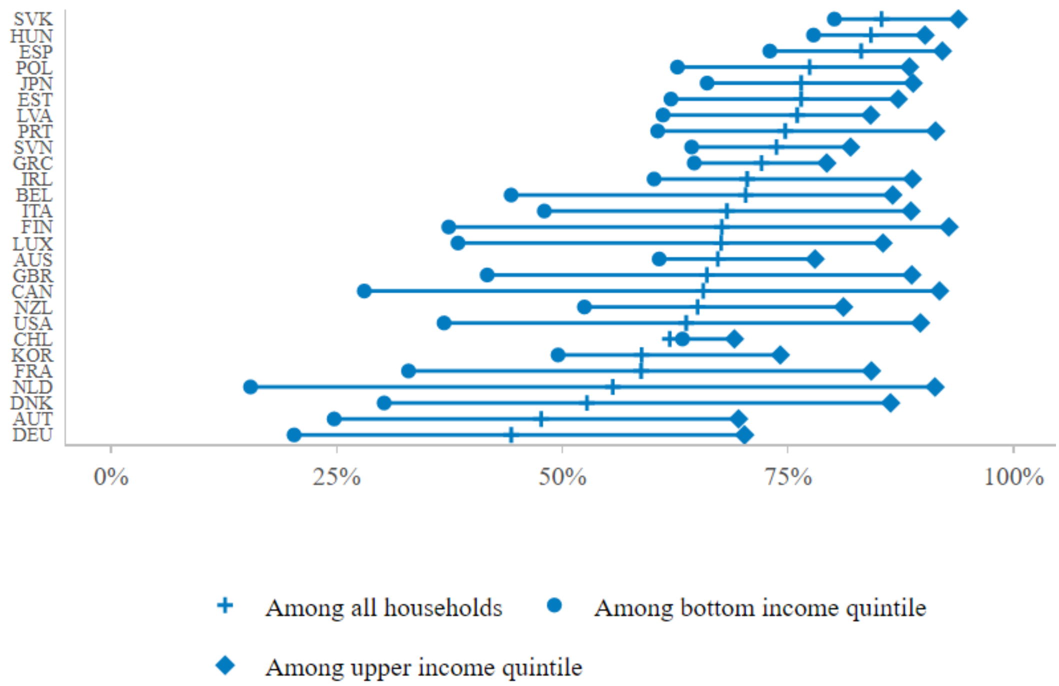

Figure 1.2: Homeownership across the income distribution. Source: OECD (2016)

low-income households harder to purchase houses than others. Taxing less on houses along with low transaction costs would encourage low-income households to purchase houses in particular. Hence, taxing housing appropriately might improve the homeownership rates among the low income households since taxes on property would affect house buying decisions as one can expect.[3] In this paper, we study the implications of taxing the housing assets proportionally and progressively.

This paper aims to examine the effect of different combinations of progressive income tax and property tax on housing with mortgage interest deduction. To do so, we follow a string of literature that incorporated the housing market into a large scale overlapping generation model with heterogeneous agents. Households in the model economy are differentiated by age and earning dynamics and derive utility from non-durable consumption goods and shelter services. To model the housing market, we follow Sommer and Sullivan (2018), which distinguish themselves from the past literature on the housing market by allowing for endogenously generated house prices and rents. In this housing market, all houses are eligible for renting or purchasing, as in Sommer et al. (2013), Cho et al. (2021), and Kaplan et al. (2020). In our model, there are three types of households: landlords, owner-occupiers and renters. The rental units cannot exceed the owner-occupied units. The rental market is modelled as one competitive firm following Kaplan et al. (2020). The model also features a progressive tax system that imitates the U.S. tax code by allowing tax deductions specific to each type of household. Government finances its expenditure by taxing households' gross income and housing assets. The government revenue is then used to provide public goods. In order to study the effect of different levels of progressivity, we model the U.S. tax system following Benabou (2002).

Our model is calibrated to the U.S. economy and generates the homeownership rates, the landlord rates, and the fraction of homeowners with gross mortgage debt close to the data. We then conduct seven counterfactual experiments to analyze the implications of tax reform on house prices, rental prices, homeownership rate, and social welfare. In the benchmark economy, we use a progressive income tax with a proportional property tax rate system. In the first and second experiments, we decrease and increase the proportional property tax rate, respectively, to see how proportional property taxes change households'

[3] In the U.S., housing taxation (property tax) is a proportional tax that is applied annually to the market value of each property. The property tax rate varies across the states. According to Stebbins and Sauter (2020), the property tax in 2016 ranges from 0.32% to 2.31%.

housing decisions. The two experiments generate results similar to those in Sommer and Sullivan (2018), where two opposing forces determine the homeownership decision as a result of the change in property tax rate. First, an increase in the property tax rate raises the overall cost for being a homeowner. Second, a decline in house prices implies a decrease in the cost of homeownership. These two strengths together defines the overall response when the property tax rate increases. As a result, a decrease in the property tax rate increases the homeownership rate and generates welfare gains.

Cho et al. (2021) use a similar model as Sommer and Sullivan (2018) to study the role of negative gearing calibrating to the Australian economy. In contrast to Sommer and Sullivan (2018) and Cho et al. (2021), we replace the proportional property tax system with a progressive property tax system by incorporating Benabou (2002) structure in the third, fourth, and fifth experiments. Intuitively, with a progressive property tax system, households with more housing assets are taxed more while households with less housing assets are taxed less. Hence, renters face lower property taxes and have more incentive to become homeowners. At the same time, incorporating a progressive property tax system decreases house prices and generates welfare gains. As the progressivity of property tax increases, the house prices decreases and the homeownership rate increases. Higher progressivity also generates higher welfare gains. One of the experiments in Rotberg (2021) also replaces the proportional housing tax rate with progressive housing tax rate similar to us. Yet, Rotberg (2021) uses a simple structure: setting up an exemption threshold. He shows a similar result that incorporating progressive housing taxation decreases house prices and generates welfare gains.

Previously, a number of literature have discussed the importance of progressive tax systems without considering the housing sector. For instance, Conesa and Krueger (2006), Gervais (2012), Kindermann and Krueger (2014), and Guner et al. (2016) studied the role of progressive income taxation's impact on labour, leisure and savings decisions. As a crucial part of households' wealth, housing decisions cannot be ignored. In the last two experiments (the sixth and seventh experiments), we decrease and increase the value of income tax progressivity, respectively. Our results show that with an increase in the progressivity of the income tax system, low income households are taxed less. Hence, with more after-tax income, low income households are more willing to purchase houses. As a result, an increase in income tax progressivity increases the homeownership rate and generates welfare gains. A decrease in progressivity generates the exact opposite results.

In sum, we find that higher progressivity on income and property tax help improve social welfare. In other words, due to the nature of wealth inequalities, no matter for property or gross income, taxing more on wealthier and less on poorer is beneficial.

The rest of the paper is organized as follows. Section 1.2 describes the computational model. Section 1.3 discusses the calibration of the model parameters. Section 1.4 discusses the results. Section 1.5 concludes the paper.

1.2 Model

In this section, we generate an overlapping generation model with heterogeneous agents involving the housing market following Sommer and Sullivan (2018). For simplicity, the model assumes agents work with the same hours but face uninsurable idiosyncratic income shocks. They receive utility from the consumption of nondurable goods and shelter service from the housing. It does not matter agents rent or own a house. In every period, agents make the decision on the amount of consumption, shelter service, homeownership, mortgage size, and deposits. Households take advantage of itemized tax deductions for mortgage interest and property tax payments. Although homeownership is more favourable than renting, low income households face a budget constraint that holds them back from investing in housing. We model the progressive U.S. income tax system following Benabou (2002).

1.2.1 Households

Demographics. We have overlapping generations in the economy. Time is assumed to be discrete with one year intervals. In each period, a generation is born. The population grows at a constant rate of n. Each household can live up to J periods.

Preferences. Following from the previous studies of housing choices and consumption such as Díaz and Luengo-Prado (2008), Fernandez-Villaverde et al. (2011), and Sommer et al. (2013), we model the household's preference over non-durable consumption (c) and shelter service (s) in the following form:

$$U(c,s) = \frac{(c^{\alpha}s^{1-\alpha})^{1-\sigma}}{1-\sigma}. \tag{1.1}$$

Labour income. The labour income process follows Heathcote (2005), Sommer et al. (2013), and Sommer and Sullivan (2018). Agents move from one labour income level w to another w' (with) due to stochastic aging and productivity shocks.

Aging shocks consist of probabilities of transitioning from one productivity state $w_j \in W$ to another. The probabilities are given by $\psi = \frac{1}{zL}$, where z is the proportion of the population with state w and L is the expected lifetime. In addition, the conditional probability matrix $P(w'|w)$ captures the transition from state w to state w' caused by productivity shocks. An overall probability is then defined as $\phi(w'|w)$, which is equal to the likelihood of transitioning from one state to another due to an aging shock, and the likelihood of making this transition due to a productivity shock conditional on not aging. This overall transition probability matrix is expressed as follows:

$$\Phi = \underbrace{\begin{bmatrix} 0 & \psi_1 & 0 & 0 \\ 0 & 0 & \ddots & 0 \\ 0 & 0 & 0 & \psi_{J-1} \\ \psi_J & 0 & 0 & 0 \end{bmatrix}}_{\text{transition due to aging shock}} + \underbrace{\begin{bmatrix} (1-\psi_1) & 0 & 0 & 0 \\ 0 & \ddots & 0 & 0 \\ 0 & 0 & (1-\psi_{J-1}) & 0 \\ 0 & 0 & 0 & (1-\psi_J) \end{bmatrix} P}_{\text{transition due to productivity shock}} \tag{1.2}$$

with the fractions z as the solutions to the equation system $z = z\Phi$.

In addition, young agents are born as renters with no assets and no bequests. When households die, all left-over financial and housing assets are confiscated by the government. These assets will not be used to finance the households in any way.

Assets and market arrangements. At the beginning of each period, households have three kinds of assets: houses ($h \geq 0$), deposits ($d \geq 0$), and mortgages ($m \geq 0$). They earn from their deposit at an interest of r. Mortgage debt is serviced at a risk free rate r plus a mortgage interest rate κ, which gives the mortgage rate as $r_m = r + \kappa$. Households then make optimal decisions on their assets at h', d', and m' upon knowing their idiosyncratic earning shocks of the time.

Housing assets are available in $K+1$ discrete sizes, $h \in \{0, h(1), h(2), \ldots, h(K)\}$, in ascending order. The house price is p per housing unit, which is determined endogenously by solving the housing market equilibrium. For households with positive housing units, the unit for self-use is considered the shelter service (s) they obtain. A household can choose not to own a house but purchase shelter service in the rental market with rental price ρ, which is again determined endogenously by the rental market clearing condition. We allow households to rent a fraction of a house in the rental market, like a room. Thus the minimum rental size, $\underline{s}$, can be smaller than the minimum housing unit $h(1)$, i.e., $\underline{s} < h(1)$. Renters, yet are not restricted in renting any larger shelter sizes, thus $s \in \{\underline{s}, h(1), h(2), \ldots, h(K)\}$. The household's type is determined by the numerical relation between their choice over the housing unit to be purchased, and the amount of shelter service purchased $(h' - s)$.[4] A renter does not own any house $(h' = 0)$. Since we assume there are no homeless households in this model, renters always have higher shelter service obtained than housing units $(h' < s)$. An owner-occupier use all their purchased housing unit as shelter $(h' = s)$. Moreover, a landlord leases their spare housing units as renting investments $(h' > s)$ where $h' - s$ is the amount for renting. This can be summarized as

$$\text{Household} = \begin{cases} \text{Renter} & \text{if } h' < s \\ \text{Owner-occupier} & \text{if } h' = s \\ \text{Landlord} & \text{if } h' > s \end{cases}$$

In this way, the supply of renting units are endogenously determined in the market since the landlords are not allowed to consume more shelter service than the housing stock $s \leq h'$. Hence renters are not allowed to purchase investment properties.

Several costs are incurring in the housing market. First, a cost incurs when buying and selling a house. Households pay a transaction fee at the amount of τ_b upon buying and at the amount of τ_s upon selling. Both costs are proportional to the house value. Thus, the transaction costs are $\tau_b p h'$ and $\tau_s p h$, respectively. The total transaction cost is the sum of the two. It creates a significant welfare loss among households. Secondly, houses require maintenance. The maintenance cost (M) is used to offset the housing depreciation. Hence, $M(ph') = \delta_h p h'$, where δ_h is the depreciation rate of houses, and it is proportional to the house value. The third cost applies to the landlords only. We follow Chambers

[4] When households making decisions, they choose whether to purchase houses in the next period, therefore we use h' here.

et al. (2009) and Sommer and Sullivan (2018), which capture a load of managing and maintaining rental properties with fixed cost θ in each period.

To lower the burden of the consumers, housing can also be financed by mortgage borrowing through a form of Home Equity Line of Credits (HELOCs). The absence of a complete financial market in the model implies that all borrowing must be attained through utilising existing housing stock as collateral. As a result, borrowers have to meet a minimum down payment of eph' to take up a loan, where $e \in (0, 1)$ is the minimum equity requirement. The constraint on mortgage debt, m' can be expressed as follows:

$$m' \leq (1 - e)ph'. \tag{1.3}$$

The down payment requirement effectively rules out anyone who is not capable of affording a house. Any household who wish for owning a house must pay for a fraction e of the house value ph'. Furthermore, households who want to purchase a new house or move to the rental market must clear their debt before taking any further actions. Following Sommer and Sullivan (2018), we impose the following condition on mortgage constraints:

$$m' \mathbb{1}_{\{(m'>m) \bigcup (h' \neq h)\}} \leq (1 - e)ph'. \tag{1.4}$$

This equation implies that existing homeowners do not need to change their mortgage debt decisions when house price falls as long as they hold on to their housing stocks. On the other hand, when house price rises, homeowners can increase their mortgage loan borrowing.

1.2.2 Government

Following Benabou (2002), we model U.S. tax system as follows:

$$T(w, \tilde{y}) = \tau_p w + \tilde{T}(\tilde{y}), \tag{1.5}$$

where w is the wage rate; τ_p is the payroll tax rate; and

$$\tilde{T}(\tilde{y}) = \tilde{y} - \lambda_0 \tilde{y}^{1-\lambda_1}. \tag{1.6}$$

In $\tilde{T}(\tilde{y})$ (equation (1.6)), $\tilde{y}$ represents total taxable income; λ_0 determines the average level of taxation; and λ_1 is the progressivity parameter. Rewriting the progressive part of the tax system $\tilde{T}$, we get

$$\frac{1-\tilde{T}'}{1-\tilde{T}/\tilde{y}} = 1-\lambda_1.^5 \tag{1.7}$$

Let y be the sum of labour income w, interest income rd, and taxable rental income y_r:

$$y = w + rd + y_r. \tag{1.8}$$

In the U.S. economy, landlords are treated as business entities since they obtain income from renters. Hence, the property that landlords own can be separated into two parts for tax purposes: one part used as a shelter and the other part used for renting out. Each landlord must report all their rental incomes. As such, the rental income net of tax-deductible expenses for landlords can be defined as the following:

$$\begin{aligned} y_r = \underbrace{\rho(h'-s)}_{\text{gross rental income}} - \Big\{ \underbrace{r_m m(\frac{h'-s}{h'})}_{\text{mortgage interest}} + \underbrace{\tau_h p(h'-s)}_{\text{rental proportion of property tax}} + \\ \underbrace{\delta_h p(h'-s)}_{\text{property maintenance cost}} + \underbrace{\tau_D p(h'-s)}_{\text{depreciation allowance}} \Big\}, \end{aligned} \tag{1.9}$$

where $\rho(h'-s)$ is the gross rental income, $r_m m(\frac{h'-s}{h'})$ is the mortgage interest of rental space $(h'-s)$, and $\tau_h p(h'-s)$ is the rental space property tax. $\delta_h p(h'-s)$ represents the rental property maintenance cost. Moreover, $\tau_D p(h'-s)$ represents the depreciation allowance on rental space, where τ_D is the proportion of the rental property that is tax-deductible for landlords according to the U.S. tax code.

Total taxable income is defined as total income minus allowable deductions

$$\tilde{y} = \max[0, y - \chi(x)], \tag{1.10}$$

for $x \in \{\text{Renter, Owner-occupier, Landlord}\}$. $\tilde{y}$ is non-negative since no tax is refundable. The term $\chi(x)$ states the allowable deductions and is different for renters, owner-occupiers,

[5] We can have regressive ($\lambda_1 < 0$), flat ($\lambda_1 = 0$), progressive ($0 < \lambda_1 < 1$), or full redistribution ($\lambda_1 = 1$) in this tax system setting λ_1 accordingly. In a regressive tax system, the average tax rate ($\tilde{T}/\tilde{y}$) exceeds the marginal tax rate ($\tilde{T}' = \partial\tilde{T}/\partial\tilde{y}$) since $1-\lambda_1 > 0$. It is the opposite for a progressive tax system. In the flat tax system, the average tax rate equals the marginal tax rate, which is $1-\lambda_0$. With full-redistribution tax system, the marginal rate is 1, and the tax will be just $\tilde{T} = \tilde{y} - \lambda_0$.

and landlords.

Renters' deduction. Renters can deduct the amount of

$$\chi(R) = \xi + \xi_e, \tag{1.11}$$

where ξ and ξ_e are standard deduction and personal exemption, respectively.

Owner-occupiers' and landlords' deduction. Owner-occupiers and landlords are going to have the same personal exemption (ξ_e), while they can choose between a standard deduction (ξ) or an itemized deduction (ξ_i). Such itemized deduction consists of deductions in mortgage interest payments ($\tau_m r_m m \frac{s}{h'}$) and property taxes for owner-occupied space ($\tau_h ps$), i.e.

$$\xi_i = \tau_m r_m m \frac{s}{h'} + \tau_h ps. \tag{1.12}$$

Hence, the total deduction can be written as

$$\chi(O, L) = [\xi_e + \max\{\xi, \xi_i\}]. \tag{1.13}$$

We convert the dollar values in the U.S. tax code into units by normalizing using the average wage. Let $\bar{w}_d$ be the average wage, let ξ_d be the standard deduction specified in the U.S. tax code, and let $\bar{w}$ be the average wage in the model. The standard deduction in the model then can be calculated as

$$\xi = \left(\frac{\bar{w}}{\bar{w}_d}\right)\xi_d. \tag{1.14}$$

Note that the government revenue is collected not to be used for households. So it will not affect households' optimal decisions in any period.

1.2.3 Dynamic Problem

Households enter to each period with a housing stock $h \geq 0$, accumulated deposits $d \geq 0$, and unpaid mortgage debt $m \geq 0$. By observing the idiosyncratic wage shock w and the current price vector (q, ρ), households make optimal choices by solving the optimization problem:

$$v(w,d,m,h) = \max_{c,s,h',d',m'} U(c,s) + \beta \sum_{w' \in \mathcal{W}} \phi(w'|w) v(w',d',m',h') \tag{1.15}$$

subject to

$$\begin{aligned} c + &\rho(s-h') + d' - m' + p(h'-h) + \mathbb{1}_s \tau_s ph + \mathbb{1}_b \tau_b ph' \\ \leq & w + (1+r)d - (1+r_m)m - T(w,\tilde{y}) - \tau_h ph' - M(ph') - \theta \mathbb{1}_{h'>s} \end{aligned} \tag{1.16}$$

$$m' \mathbb{1}_{\{(m'>m) \bigcup (h' \neq h)\}} \leq (1-e)ph'. \tag{1.17}$$

$$m' \geq 0 \tag{1.18}$$

$$d' \geq 0 \tag{1.19}$$

$$h' \geq s \quad \text{if} \quad h' > 0 \tag{1.20}$$

In each period, households choose the optimal levels of non-durable consumption ($c > 0$), shelter services ($s > 0$), housing stocks (h'), deposits (d'), and mortgage debts (m'). Equation (1.16) represents the budget constraint. In which, $\rho(s-h')$ can be a rental expense for renters or rental income that landlords receive. The term $p(h'-h)$ represents the change in housing asset value within the current period. Transaction costs incur whenever households are buying or selling houses, with the amount $\tau_s ph$ and $\tau_b ph'$, respectively. Households' labour income w follows the transition process $\phi(w'|w)$. Households get rd amount of interest return on deposits, paying $r_m m$ as the interest of outstanding mortgage debt and federal and property taxes at the amount of $T(w,\tilde{y}) + \tau_h ph'$. $M(ph')$ is the maintenance fee for homeowners and θ represents the fixed cost for landlords. Equation (1.4) states the collateral requirement.

1.2.4 Housing Supply

To complete the model, a construction sector that governs the aggregate housing supply is introduced. There are two key assumptions. One is that the growth in U.S. housing stock is greatly caused by population growth. Recall that the population growth rate is n. The other is that the aggregate housing stock (H) is also determined by the residential investment (I) as a response to changes in house prices. The aggregate housing stock in the next period is given by

$$H' = H + I, \tag{1.21}$$

where

$$I = f(p, \varepsilon)H \tag{1.22}$$

with $f(p, \varepsilon)$ representing the constant elasticity supply function for residential investment; and the parameter ε represents the elasticity of residential investment with respect to the house price (p). Since house prices change due to housing tax reforms, so does residential investment, and hence the aggregate housing stock. In addition, since it is not allowed to make residential investment more than the aggregate housing stock, the residential investment, I, must be a proportion of the current housing stock, H. Note that the depreciation of housing stock has already been offset by the maintenance cost. At the steady state, the housing supply meets the restriction of $f(p^*, \varepsilon) = n$, so the housing stock per capita is constant. In this way, the aggregate housing supply responds to the population growth and any changes in tax structures.

1.2.5 Stationary Equilibrium

Each individual's state vector is given by $\mathbf{s} = (w, d, m, h)$. $w \in \mathcal{W} = \{w_1, w_2, \ldots, w_7\}$ stands for household wage. $d \in \mathcal{D} = \mathbb{R}_+$ is the deposit holding. $m \in \mathcal{M} = \mathbb{R}_+$ is the mortgage balance. And $h \in \mathcal{H} = \{0, h(1), h(2), \ldots, h(K)\}$ represents the housing stock. The entire state space is given by $\mathcal{S} = \mathcal{W} \times \mathcal{D} \times \mathcal{M} \times \mathcal{H}$. Now, let μ be a probability measure on $(\mathcal{S}, \mathcal{B}_s)$, where $\mathcal{B}_s$ is the Borel σ-algebra. For every Borel set $B \in \mathcal{B}_s$, let $\mu(B)$ indicate the mass of agents whose individual state vectors lie in B. We can define a transition function $P : \mathcal{S} \times \mathcal{B}_s \to [0, 1]$ so that $P(\mathbf{s}, B)$ defines the probability that a household with state $\mathbf{s}$ will have an individual state vector lying in B next period. A stationary equilibrium is a collection of value functions $v(\mathbf{s})$, an individual decision rule $\{c(\mathbf{s}), s(\mathbf{s}), d'(\mathbf{s}), m'(\mathbf{s}), h'(\mathbf{s})\}$, a stationary distribution μ, and price vector (p^*, ρ^*) such that:[6]

1. The allocations $c(\mathbf{s}), s(\mathbf{s}), d'(\mathbf{s}), m'(\mathbf{s}), h'(\mathbf{s})$ solve the individual's optimization problem for state vector $\mathbf{s}= (w, d, m, h) \in \mathcal{S}= \mathcal{W} \times \mathcal{D} \times \mathcal{M} \times \mathcal{H}$.

2. The housing and rental markets clear:

$$\begin{aligned} \int_{\mathcal{S}} h'(\mathbf{s})d\mu = H, \\ \int_{\mathcal{S}} (h'(\mathbf{s}) - s(\mathbf{s}))d\mu = 0, \end{aligned} \tag{1.23}$$

   where $\mathcal{S} = \mathcal{W} \times \mathcal{D} \times \mathcal{M} \times \mathcal{H}$.

3. μ is a stationary probability measure induced by decision rules consistent with household behaviour, such that $\mu(B) = \int_{\mathcal{S}} P(\mathbf{s}, B)d\mu$ for any Borel set $B \in \mathcal{B}_s$.

1.3 Calibration

The model is calibrated in two steps. First, we take the external parameters sourcing from the previous literature and data, including the estimated elasticity of residential investment with respect to house prices for the housing supply from Sommer and Sullivan (2018). Then we calibrate the remaining parameters to match the baseline steady state equilibrium with the data.

1.3.1 External calibration

Table 1.1 summarizes the exogenous parameters.

Demographics. The model period is set to one year. Household population grows at rate $n = 0.01$. Households are assumed to live for 50 periods.

Preferences. The coefficient of the constant relative risk aversion (CRRA) function, σ, is set to 2.5. The Cobb-Douglas preference for non-durable goods (α) and the discount factor (β) are calibrated by hitting the certain moments (see Section 1.3.2).

[6] House price p^* and rental prices ρ^* are determined by clearing the housing and rental markets.

Table 1.1: Summary of exogenous parameters

Parameter	Description	Value	Source
ρ_w	Autocorrelation of labor income shocks	0.90	Sommer & Sullivan (2018)
σ_w	Standard deviation of labour income shocks	0.20	Sommer & Sullivan (2018)
σ	Risk aversion	2.50	Sommer & Sullivan (2018)
e	Down payment requirement	0.20	Sommer & Sullivan (2018)
τ_s	Selling cost rate	0.07	Gruber & Martin (2003)
τ_b	Buying cost rate	0.025	Gruber & Martin (2003)
r	Risk-free interest rate	0.04	Sommer & Sullivan (2018)
κ	Mortgage interest rate spread	0.015	Sommer & Sullivan (2018)
r_m	Mortgage rate	0.055	$r_m = r + \kappa$
δ_h	Maintenance cost rate	0.015	Díaz & Luengo-Prado (2008)
τ_p	Payroll tax rate	0.076	Sommer & Sullivan (2018)
τ_h	Proportional property tax rate	0.01	Díaz & Luengo-Prado (2008)
τ_m	Mortgage deductibility rate	1.00	By assumption
τ_D	Deductibility rate for rental property depreciation	0.023	Davis & Heathcote (2007)
n	Population growth rate	0.01	Sommer & Sullivan (2018)
λ_0	Average tax control	0.902	Guner et al. (2014)
λ_1	Tax progressivity	0.036	Guner et al. (2014)
ε	Housing supply elasticity	0.902	Sommer & Sullivan (2018)

Labour income. A household i with age a receives wage $w_{i,a}$ following the process:

$$\log w_{i,a} = \eta_a + \zeta_{i,a}, \tag{1.24}$$

where η_a is the aging shock. The stochastic process for household labour market productivity $\zeta_{i,a}$ follows an AR(1) process:

$$\zeta_{i,a} = \rho_w \zeta_{i,a-1} + \nu \quad \text{with} \quad \nu \sim NID(0, \sigma_w^2), \tag{1.25}$$

with the auto-correlation coefficient, ρ_w, and the standard deviation of innovation, σ_w equal to 0.90 and 0.20, respectively.

Assets and market arrangements. Gruber and Martin (2003) use the Consumer Expenditure Survey (CES) data and state that the average buying and selling costs for housing are 2.5 percent and 7 percent, respectively. Hence, the parameters for the transaction costs for buyers and sellers are set to $\tau_b = 0.025$ and $\tau_s = 0.07$ accordingly. Following Díaz and Luengo-Prado (2008), the rate of maintenance cost as to offset the depreciation is set to $\delta_h = 0.015$. Landlords' fixed cost, θ, is calibrated to match certain target moments (see Section 1.3.2). The down payment requirement, e, is set to 20 percent, which is consistent with the practice in many advanced economies.[7] Following Sommer and Sullivan (2018), the mortgage rate r_m is calculated as $r_m = r + \kappa$, in which $r = 0.04$ is the return rate on deposit; and $\kappa = 0.015$ represents the mortgage interest rate spread. These together give the mortgage rate $r_m = 0.055$.

Government. Using the 2007 American Community Survey, Díaz and Luengo-Prado (2008) report that the housing property tax rate is 0.95 percent. Thus, in this baseline model, we set the property tax rate at $\tau_h = 0.01$, where properties are taxed proportionally to their house value. Following Sommer and Sullivan (2018), we assume that the mortgage interest payment is fully tax-deductible, i.e., $\tau_m = 1$. We set the depreciation rate of rental property for tax purposes $\tau_D = 0.023$ and the payroll tax rate $\tau_p = 0.076$. Following Guner et al. (2014), we set the tax system parameters $\lambda_0 = 0.902$ and $\lambda_1 = 0.036$. Notice λ_0 captures the average tax rate, and λ_1 captures the tax progressivity.

1.3.2 Calibrated Parameters

Table 1.2: Calibrated parameters and target moments

Parameter		**Value**
Discount factor (β)		0.9876
Consumption share (α)		0.6750
Fixed cost for landlords (θ)		0.0494
Moment	**Data**	**Model**
Homeownership rate	0.65	0.65
Landlord rate	0.10	0.09
Fraction of homeowners with mortgage debt	0.65	0.65

Table 1.2 summarizes the calibrated parameters along with calibration target moments. The Cobb-Douglas consumption share (α), the discount factor (β), and the landlord's fixed cost (θ) are calibrated jointly as a vector $\Theta = \{\alpha, \beta, \theta\}$ to match the following moments in the data: the homeownership rate, the landlord rate, and the fraction of homeowners in mortgage debt. According to USCB (2021), the homeownership rate increased from 66 percent in 1997 to 69 percent in 2005. Then it decreases to 63 percent in 2016 and raises again afterwards. The most recent data shows a 65.4 percent homeownership rate in the second quarter of 2021. Hence, we set the homeownership target rate equals to 0.65. Using

[7] As there is no loan approval process in this model, e acts as a substitute for the overall tightness of mortgage underwriting standards.

the American Housing Survey data, Chambers et al. (2009) report that approximately 10 percent of the homeowners receive rental incomes. Following them, we set the landlord rate target as 0.10. These two targets then jointly imply that the renter rate is 0.35 and the owner-occupier rate is 0.55.[8,9] We set the same target of the fraction of homeowners with debt to 0.65 as in Sommer and Sullivan (2018).

1.4 Results

1.4.1 Benchmark model

We calibrated the model economy to the U.S. economy targeting the following moments: the homeownership rate, the landlord rate, and the fraction of homeowners with debt (see Table 1.2). In addition, we hit the following three moments that are not targeted in the model: the mean loan-to-income ratio, mean loan-to-house value ratio and mean house value-to-income ratio (see Table 1.3).[10] Our baseline model generates an average federal tax rate of 0.19, which is in line with the 2018 data reported by CBO (2021). Garner and Verbrugge (2009) report that the house price-to-rent ratio (the relative price of owning a house to renting) has a value between 8 to 15.5 with a mean of 12.[11] Our model generates the house price-to-rent ratio as 12.6 (see Tables 1.4, 1.5, and 1.6). Notice that the house price-to-rent ratio shows the willingness to move from renting to homeownership. If the house price-to-rent ratio increases (decreases), ceteris paribus, purchasing a house is considered relatively more (less) expensive than renting. Hence renters have less (more) incentive to purchase houses. The median house value-to-income ratio from our baseline model is 2.8 (see Tables 1.4, 1.5, and 1.6). It is close to 2.7, reported in the American Housing Survey for the United States for 2011 (USCB (2013)).

1.4.2 Counterfactual Experiments

Here, we examine the effects of several counterfactual tax reforms on house prices, rental prices, homeownership, and household welfare.

[8] The renter rate = 1− the homeownership rate.
[9] The owner-occupier rate = the homeownership rate − the landlord rate.
[10] The data comes from Survey of Consumer Finances 1989-2019 (SCF (2021)).
[11] Garner and Verbrugge (2009) conducted the statistics from Consumer Expenditure Survey data.

Table 1.3: Moments not targeted in calibration

Moments	Data	Model
Mean loan to income ratio	1.57	1.45
Mean loan to house value ratio	0.34	0.36
Mean house value to income ratio	4.63	4.35

Notes: Data shows statistics computed from Survey of Consumer Finances 1989-2019

Our experiments can be separated into three groups. In the first group of experiments (E_1 and E_2), we assume the property tax is proportional to the house value ph'. We set the flat property tax rate $\tau_h = 0.005$ in E_1 and $\tau_h = 0.015$ in E_2. In both experiments, we keep the progressive income tax system unchanged. Therefore, E_1, Baseline, and E_2 represent an increasing trend in the proportional property tax rate. In the second group of experiments (E_3, E_4, and E_5), we replace the proportional property tax with a progressive property tax system that has the same functional form as the income tax system (see equation (1.6)). More precisely, we use the following functional form for the progressive property tax:

$$\tilde{T}_h(ph') = 0.1 \times (ph' - \lambda_0 (ph')^{1-\lambda_2}),$$

where 0.1 is used for scaling purpose so that the property taxes falls in a range that suits the U.S. data. λ_2 in the equation is similar to λ_1 in equation (1.6), which captures the progressivity of the tax function.[12] In these experiments (E_3, E_4, and E_5), we set λ_2 to 0.018, 0.036, and 0.054, respectively. In the last group of experiments (E_6 and E_7), we keep the progressivity of the property tax system intact ($\lambda_2 = 0.036$) and examine the implications of changes in the progressivity of the income tax system setting to $\lambda_1 = 0.018$ and $\lambda_1 = 0.054$, respectively. In order to conduct welfare analysis, we use the consumption equivalent variation (CEV) measure. It is defined as the uniform increase in consumption a household needs to be indifferent between being born into a reformed economy and being born in the baseline economy. The functional form of the CEV is given as follows

$$cev = \left(\frac{V_e}{V_b}\right)^{\frac{1}{\alpha(1-\sigma)}} - 1, \tag{1.26}$$

where V_e represents the value function of the counterfactual experiments and V_b represents the value function of the baseline model. Tables 1.4, 1.5, and 1.6 summarize the prices,

[12] The progressivity λ_2 governs the curvature of property tax function.

economic aggregates, and CEVs for the three groups of counterfactual experiments, respectively.[13]

Table 1.4: The effect of varying proportional property tax

	Baseline	Experiment 1		Experiment 2	
$\lambda_1 = 0.036$	$\tau_h = 0.01$	$\tau_h = 0.005$	% change	$\tau_h = 0.015$	% change
House price	3.375	3.587	+6.3%	3.196	-5.3%
Rent	0.268	0.268	0.0%	0.269	+0.4%
Price-rent ratio	12.594	13.359	+6.1%	11.904	-5.5%
Homeowners%	0.654	0.658	+0.6%	0.646	-1.2%
Renter%	0.346	0.342	-1.2%	0.354	+2.3%
Owner-occupied%	0.559	0.567	+1.4%	0.549	-1.8%
Landlord%	0.093	0.091	-2.2%	0.097	+4.3%
Median $\frac{housevalue}{wage}$	2.814	2.991	+6.3%	2.665	-5.3%
Homeowners in debt%	0.649	0.675	+4.0%	0.623	-4.0%
Average mortgage	0.928	1.035	+11.5%	0.811	-12.6%
cev	-	0.15%		-0.33%	
$Pr(cev > 0)$	-	49.24%		16.75%	

Notice that in the first two counterfactual experiments, the income tax system is fixed, and the property tax rate is set to a lower value $\tau_h = 0.005$ in E_1 and a higher value $\tau_h = 0.015$ in E_2. Table 1.4 shows the results from these two experiments compared to the baseline. When decreasing the property tax rate from 1 percent (in the baseline) to 0.5 percent (in E_1), the house price increases by 6.3 percent since the cost of ownership is decreased dramatically. In addition, the rent is not changed much. These two effects together cause the house price-to-rent ratio to increase by 6.1 percent. We also observe a 0.6% rise in the homeownership rate. Intuitively, the increased house prices lead to increases in better investment returns with lower taxes. As a result, households are more willing to become homeowners for investment purposes.

On the other hand, when the property tax rate is increased to 1.5 percent (in E_2), we observe a 5.3 percent decrease in house prices and a 0.4 percent increase in rents. Hence, we observe a 5.5 percent decrease in the house price-to-rent ratio with no surprise. In addition, we observe a 1.2 percent fall in the homeownership rate. This result is in contrast to that of Sommer and Sullivan (2018). They state that a decrease in the house price-to-rent ratio would increase the homeownership rate since ownership is cheaper relative to renting.

Intuitively, increasing the property tax rate raises the overall cost of being a homeowner, although some costs are reduced due to the corresponding decrease in house prices. To

[13] The results of the detailed distribution of cev_i across households are shown in Figures A.1 to A.7 in the appendix.

be more specific, increasing the property tax rate increases the property taxes paid by homeowners, decreasing housing demand and house prices. Furthermore, the decrease in house prices reduces the following costs: the transaction costs for entering the housing market ($\tau_b ph'$), the maintenance cost ($\delta_h ph'$), and the down payment (eph'). Hence, there is a trade-off between the increased property taxes and the reduced house prices that determines the homeownership rate. Our results show that the increase (decrease) in property taxes due to the increase (decrease) in property tax rates dominates the decrease (increase) in house prices. As a result, a decrease (increase) in the homeownership rate is observed. In addition, the change in house prices is essential for mortgage debt decisions. An increase (decrease) in the house price implies an increase (decrease) in the fraction of homeowners in debt and average mortgage.[14] Moreover, as Table 1.4 shows, the overall welfare (CEV) decreases since most households experience welfare loss when the proportional property tax rate increases.[15]

Table 1.5: The effect of varying progressivity of property tax

	Baseline	Experiment 3		Experiment 4		Experiment 5	
$\lambda_1 = 0.036$	$\tau_h = 0.01$	$\lambda_2 = 0.018$	% change	$\lambda_2 = 0.036$	% change	$\lambda_2 = 0.054$	% change
House price	3.375	3.210	-4.9%	3.085	-8.6%	2.959	-12.3%
Rent	0.268	0.269	+0.3%	0.271	+1.1%	0.271	+1.1%
Price-rent ratio	12.594	11.947	-5.1%	11.400	-9.5%	10.925	-13.3%
Homeowners%	0.654	0.699	+6.9%	0.721	+10.2%	0.736	+14.1%
Renter%	0.346	0.301	-13.0%	0.279	-19.4%	0.264	-23.7%
Owner-occupied%	0.559	0.618	+10.6%	0.651	+16.5%	0.672	+20.2%
Landlord%	0.093	0.081	-12.9%	0.070	-24.7%	0.064	-31.2%
Median $\frac{housevalue}{wage}$	2.814	2.768	-1.9%	2.753	-2.2%	2.932	+4.2%
Homeowners in debt%	0.649	0.632	-2.6%	0.611	-5.9%	0.590	-9.1%
Average mortgage	0.928	0.822	-11.4%	0.724	-22.0%	0.656	-29.3%
cev	-	0.39%		0.48%		0.86%	
$pr(cev > 0)$	-	50.79%		52.15%		55.05%	

In the third, fourth, and fifth counterfactual experiments (E_3, E_4, and E_5), we replace the proportional property tax $\tau_h ph'$ with a progressive tax system $\tilde{T}_h(ph') = 0.1 \times (ph' - \lambda_0 (ph')^{1-\lambda_2})$, where 0.1 is a scaling parameter; and λ_2 is the progressivity of the new property tax function. With the new property tax structure, a few elements in the model has to change accordingly. Recall that in the baseline model with the proportional property taxes, landlords deduct the rental proportion of the property tax from their rental income at the amount of $\tau_h p(h' - s)$. Moreover, the homeowners' mortgage interest deduction

[14] This result is the same for all seven experiments.

[15] As Table 1.4 shows, $Pr(cev > 0)$ is 16.75% in E_2. This means that the percentage of households experiencing no welfare gains is $1 - 16.75 = 83.25\%$.

consists of two parts: mortgage interest payment ($\tau_m r_m m \frac{s}{h'}$) and the property tax for owner-occupied space ($\tau_h ps$ previously). With the progressive property tax reform, the rental proportion of the property tax from landlords rental income becomes $\tilde{T}_h p(h' - s)$. The itemized deduction becomes $\xi_i = \tau_m r_m m \frac{s}{h'} + \tilde{T}_h(ph')\frac{s}{h'}$. By implementing such reform in the property taxes, we can tax the wealthier households more on their properties and tax the less wealthy households less on their housing assets. Hence, we can mitigate the less wealthy households' burden in paying property taxes so that they become homeowners easily.

As shown in Table 1.5, comparing the baseline case with the experiments, we observe a fall in house prices and a slight rise in rents. Together, these two effects lead to a fall in the house price-to-rent ratio when a progressive property tax is in place. Two forces are driving the results. First, a lower house price-to-rent ratio leads to a lower house price relative to the rent. Hence, purchasing a house becomes relatively less expensive. Second, due to a progressive property tax, households with low housing assets face lower property taxes. These forces work in the same direction. Therefore, a significant fraction of renters become homeowners. Since the investment part of properties is taxed more, fewer households prefer to be landlords, which results in a drop in the landlord rate. Some of the landlords may choose to sell their properties while the remaining landlords raise rents. A progressive property tax also implies an increase in the cost of households with more properties. Hence, wealthy households have less incentive to purchase more houses. This generates more opportunities for the renters to become homeowners.[16]

When the progressivity of the property tax function increased from 0.018 (in E_3) to 0.054 (in E_5), we observe that the homeownership rate is increased while the renter rate and the landlord rate are decreased. Intuitively, when we increase progressivity, the marginal cost of renters owning their first house decreases substantially. Hence, less wealthy households are more and more willing to switch from renting houses to owning houses. Moreover, the CEVs are positive and increasing with the progressiveness of the property taxes. More than half of the population are experiencing welfare gains in these reforms. The welfare gains come from the shifting wealth from the landlords to the renters.

The last two counterfactual experiments focus on the progressivity of the income tax

[16]Since wealthy households choose not to purchase more properties and even sell their properties, there is an increase in housing units available in the market. As a result, there is a drop in the house prices.

Table 1.6: The effect of varying progressivity of income tax

	Baseline	Experiment 6		Experiment 7	
$\tau_h = 0.01$	$\lambda_1 = 0.036$	$\lambda_1 = 0.018$	% change	$\lambda_1 = 0.054$	% change
House price	3.375	3.372	-0.1%	3.380	+0.1%
Rent	0.268	0.268	-0.0%	0.269	+0.4%
Price-rent ratio	12.594	12.601	+0.1%	12.573	-1.7%
Homeowners%	0.654	0.651	-0.5%	0.662	+1.2%
Renter%	0.346	0.349	+0.9%	0.338	-2.3%
Owner-occupied%	0.559	0.551	-1.4%	0.570	+2.0%
Landlord%	0.093	0.100	+7.5%	0.093	-0.0%
Median $\frac{housevalue}{wage}$	2.814	2.804	-0.4%	2.826	+0.4%
Homeowners in debt%	0.649	0.637	-1.8%	0.666	+2.6%
Average mortgage	0.928	0.889	-4.2%	0.985	+6.1%
cev	-	-0.90%		0.87%	
$pr(cev > 0)$	-	41.98%		56.52%	

system while keeping the other taxes the same as the baseline model. The proportional property tax rate is set to $\tau_h = 0.01$. We change the value of λ_1 in equation (1.6) ($\tilde{T}(\tilde{y}) = \tilde{y} - \lambda_0 \tilde{y}^{1-\lambda_1}$) to analyze the implication of income tax reform on the housing market. Intuitively, with an increase in income tax progressivity, the households with high income pay more tax while those with low income (more likely renters) pay less. As a result, renters with more after-tax income (due to the increase in income tax progressivity) are more likely to purchase houses, and landlords face higher taxes over their rental income. This, in turn, will affect the landlord rate negatively. Table 1.6 shows that when the progressivity is higher (E_7), house prices and rents increase slightly while the house price-to-rent ratio drops. This means the house price is now relatively lower than the rent, which induces renters to become homeowners. We observe the exact opposite case when we decrease the progressivity ($\lambda_1 = 0.018$ in E_6). Our results in E_6, baseline, and E_7 reveal that as the progressivity level of income tax increases, the following changes happen: house prices increase; rents drop; homeownership rates increase; renter rates decrease; landlord rates decrease; the fraction of homeowners in debt increase; and the average mortgages increase. In general, an increase in income tax progressivity improves the social welfare. More than half of the households (low income households) experience welfare gains.

1.5 Conclusion

This paper studies the effect of different tax reforms on equilibrium house prices, rents, homeownership, and welfare. Our baseline model captures essential features in the U.S. economy such as the house price-to-rent ratio, the homeownership rate, the landlord rate, the fraction of homeowners in debt, and the house value-to-income ratio.

Our results from our first two experiments show that an increase in the proportional property tax rate reduces house prices, increases rents, and decreases the house price-to-rent ratio. A fall in the house price-to-rent ratio implies a favourable environment towards owning a house. However, the decrease in costs of purchasing a house due to the decrease in house prices is dominated by the large increase in property taxes. Hence, there is a drop in the homeownership rate, although owning a house is relatively cheaper than renting. Moreover, taxing properties progressively (in third, fourth, or fifth experiments) provides renters with an incentive to purchase their own houses due to the dropped house prices and lower property taxes. In addition, increasing the progressivity of income taxes (our last two experiments) reduces the house price-to-rent ratio. Such a reduction in the relative price of ownership attracts renters with more after-tax income to purchase houses. In sum, an increase in the income tax progressivity and switching to a double progressive tax system (the tax system with both progressive income and property taxes) provide renters (most likely low income households) more incentive to become homeowners and generate welfare improvement.

In general, taxing properties progressively gives a strong incentive to renters to become homeowners. Recent literature on progressive wealth taxation by Saez and Zucman (2019) states that wealth taxation is a more powerful tool than other taxation, including income, corporate, and estate taxation, to achieve wealth concentration. Our results support the findings of Saez and Zucman (2019).

Our paper is silent on finding the optimal progressivity of the reformed tax structure. We leave this as further research. In our model, selling a property incurs a fixed selling cost. In reality, some homeowners purchase new houses for not renting out but selling out to earn the spread. A higher selling cost rate might prevent homeowners from such behaviour. It would be interesting to conduct a further experiment by incorporating a higher selling cost with a progressive property tax reform in the future.

Chapter 2

Consumption Tax and Endogenous Human Capital Accumulation

2.1 Introduction

Consumption tax is an important fiscal policy instrument for many countries. Consumption tax can generate up to 50 percent of total tax revenue in some countries (see OECD (2016)).[1] The consumption tax is ranked as the third largest source of the total tax revenue in the U.S. according to TPC (2018). However, the U.S., compared to all other OECD countries, has the lowest consumption tax contribution to the total tax revenue.[2,3] Consumption taxes on goods and services are set diversely across the world. It can be as low (4.32% in 2020) as in the U.S.; or it can be as high (16.2% in 2020) as in Hungary according to OECD (2022b). This makes us wonder about the effects of an increase in the consumption tax rate on the U.S. economy. In this paper, we study the implications of increasing the consumption tax rate and reforming the current system with a progressive consumption tax system.

The literature on consumption tax is quite rich. It has been almost two decades since literature proposed for the tax reform that replacing income taxes with a consumption tax such as Summers (1981), Gravelle (1991), and Aaron and Gale (1996). More recent literature, Kitao (2011), using a large-scale overlapping generation (OLG) model, finds that increasing the consumption tax and reducing the income tax at the same time generates

[1] For example, the consumption tax is 49.5 percent of total tax revenue in Chile.

[2] In the U.S., the consumption tax forms 15.4% of total taxes.

[3] Unlike all other OECD countries, the U.S. levies a sales tax instead of a value-added tax (VAT) as the principal consumption tax as stated in OECD (2016). It taxes all retail goods and services that consumers spend money on.

welfare gains and raises aggregate capital stock and labour supply. Instead of reducing the income taxes, Ventura (1999) and Correia (2010) replace the labour income and capital income taxes with a flat consumption tax. More specifically, Ventura (1999), using a similar model to that of Kitao (2011), finds that the flat consumption tax reform positively affects capital accumulation, aggregate labour, and inequalities. On the other hand, Correia (2010), by using a model with Gorman aggregations and infinitely lived agents, obtains a similar result that a flat consumption tax reform improves labour efficiency and reduces inequalities.[4] Without replacing the capital income tax, Shaw (2021) replaces the progressive labour income tax with a progressive consumption tax regime using an OLG model. He finds that the consumption tax reform increases the aggregate labour supply, capital, consumption, output and generates social welfare. Previous literature such as Floden (2001), Floden and Lindé (2001), and Alonso-Ortiz and Rogerson (2010) show that expanding consumption and transfer program would generate higher interest rates and lower capital-output ratios. Similarly, Nakajima and Takahashi (2020) employs an infinite horizon model and analyze the implications of an increase in the consumption tax rate on economic aggregates focusing on the difference between divisible and indivisible labour supply. They find that increasing the consumption tax rate increases the interest rate and decreases the labour supply in the divisible model, which is in contrast to the findings of Kitao (2011).

Mankiw (2015) states that taxing consumption progressively is a better way to reduce inequalities. We complement the consumption tax literature by using a model that incorporates human capital accumulation and analyzes not only flat consumption tax rate but also progressive consumption tax system. Our model differs from those of Ventura (1999), Kitao (2011), and Shaw (2021) from two dimensions. First, our model incorporates human capital accumulation. Hence, our model allows us to compare the implications of the change in the consumption tax system with and without endogenous human capital accumulation. According to Peterman (2016), human capital accumulation plays an important role in optimal taxation. Whether human capital accumulation plays a role in other tax reforms attracts our attention. Second, our model generates realistic wealth and income distribution following the current literature (see Kindermann and Krueger (2020)).

[4] By assuming Gorman aggregation, the aggregate equilibrium in Correia (2010) can be viewed as a representative household paradigm. Hence, the benchmark model assumes proportional capital and labour income taxes.

We conduct our consumption tax experiments by employing models with and without the existence of human capital accumulation. We call these two models the HCA and the non HCA models, respectively. More specifically, we incorporate 'learning-by-doing' as a form of endogenous human capital accumulation into the HCA model following Chen et al. (2011) and Peterman (2016).[5] Generating realistic wealth and income inequalities are vital to analyzing the tax policy changes. In addition, we are interested in changes in the wealth and income inequalities due to the change in the consumption tax system. As a result, we follow Kindermann and Krueger (2020) and introduce lucky states to the idiosyncratic labour shocks to generate realistic income and wealth distributions. Hence, we are able to generate realistic wealth Gini coefficients in our models.

Both HCA and non HCA models are calibrated to the U.S. economy, and they are able to match the target moments successfully.[6] We then proceed to explore the effect of an increasing consumption tax rate. We increase the consumption tax rate from 5 percent to 95 percent with 10 percent increments. We find an increasing trend in the aggregate capital stock, wages, labour supply, and output. We also observe improvements in wealth inequalities. On the other hand, we observe hump shapes in the aggregate consumption, transfers, capital-output ratio, transfer-output ratio, capital-labour ratio, and social welfare. Our results are in line with those of Ventura (1999) and Kitao (2011). We show that the directions of the results do not change in HCA and non HCA models. Finally, both models generate welfare gains when the consumption tax rates are lower than 55 percent.

In our second set of experiments, we replace the proportional consumption tax system with a progressive consumption tax system. The progressive consumption tax function we use is a step function with three brackets. First, we keep the three bracket levels unchanged and set different values for the consumption tax rates in each bracket. More specifically, we set the consumption tax rate to be zero when individuals' consumption level is less than the lower consumption threshold. We set the consumption tax rate to be one of $0.03, 0.04$, and 0.05 if the individuals' consumption lies in the second bracket (which is greater than the lower threshold and lower than the upper threshold). We then set the consumption tax rate to be one of $0.05, 0.10$, and 0.15 if the individuals' consumption is

[5] Peterman (2016) studies the effects of the optimal progressive capital and labour income tax system.

[6] We target capital-income ratio, average Frisch elasticity, average working hours, and Gini coefficients (wealth, consumption, income, and disposable income).

higher than the upper threshold. Secondly, we keep the value of the consumption tax rates unchanged and set the different threshold levels. More specifically, we set the consumption tax rates for those who consume less than a certain threshold to be zero and for those who consume more to be 5 percent. Our results from the progressive consumption tax experiments show that a more progressive consumption tax (whenever the consumption tax rate increases in the highest bracket) generates more welfare gains and reduces the consumption inequalities in both models. Intuitively, a progressive consumption tax could mitigate the low income individuals' burden on consumption expenditures. Hence, they could consume more which leads to a decrease in the consumption inequality. When the low income individuals choose to consume more, they have less remaining income to save. Hence, the wealth inequality increases as one can expect. In addition, with a higher consumption threshold, both models generate welfare losses and higher wealth inequalities but reduce the consumption inequalities. Intuitively, when there is a higher consumption threshold, more individuals are free of consumption taxes. Low income individuals tend to consume more, which leads to a decrease in the consumption inequality. On the other hand, the wealth inequality increases since low and middle income individuals save less.

This paper is organized as follows. Section 2.2 explains the model environment. Section 2.3 describes the calibration process. Section 2.4 states the experiment results. Section 2.5 concludes.

2.2 Model

We use a large scale overlapping generation model with uninsurable labour productivity risks following Peterman (2016).

2.2.1 Individuals

Demographics. Time is assumed to be discrete with one year intervals. Individuals start to work at age 20, live a finite J years, and retire at age $j_r < J$. They have probability $\psi_j < 1$ at age j to live to age $j+1$ where $j \in \mathbb{J} = \{20, 21, ..., J+20\}$. Once they die, their bequests beq_t will be redistributed automatically and equally among all living individuals.

Preferences. In each period, each individual i is endowed with no assets but one unit of time, which is divided into productive labour $(h_{i,j})$ and leisure $(1-h_{i,j})$ at age j. The wage an individual earns in the labour market is given by $w\omega_{i,j}h_{i,j}$ where $\omega_{i,j}$ is the idiosyncratic labour productivity. Following Kaplan (2012), this idiosyncratic productivity $\omega_{i,j}$ can be written as follows:

$$\begin{aligned} \log \omega^{e}_{i,j} &= \varepsilon^{e}_{j} + \zeta_i + \upsilon_t + \eta_\iota, \\ \log \omega^{l}_{i,j} &= \varepsilon^{l}_{i,j} + \zeta_i + \upsilon_t + \eta_\iota, \end{aligned} \tag{2.1}$$

where $\omega^{e}_{i,j}$ and $\omega^{l}_{i,j}$ represent the idiosyncratic labour productivity in the non HCA model and the HCA model, respectively. ζ_i represents a fixed effect known as 'ability'. ε^{e}_{j} and $\varepsilon^{l}_{i,j}$ represent the age-specific human capital. ε^{e}_{j} is exogenously determined in the non HCA model. On the other hand, $\varepsilon^{l}_{i,j}$ is determined by its lagged calibration parameter, human capital, and leisure in the HCA model. To be more specific, we set the age-specific human capital in the HCA model following Hansen and İmrohoroğlu (2009) as follows:

$$\varepsilon^{l}_{i,j} = \Theta_{j-1}(\varepsilon^{l}_{i,j-1})^{\Phi_1}(h_{i,j-1})^{\Phi_2}, \tag{2.2}$$

where Θ_j, Φ_1, and Φ_2 are the parameters that govern the sequence of $\varepsilon^{l}_{i,j}$ so that $\varepsilon^{l}_{i,j}$ in the HCA model matches with ε^{e}_{j} in the non HCA model. As individuals work more, they accumulate more human capital. The human capital is always positive since the individuals always provide a positive amount of labour in the optimization problem. The persistent shock υ_t follows an AR(1) process:

$$\upsilon_t = \rho\upsilon_{t-1} + \varepsilon_t \tag{2.3}$$

with $\varepsilon_t \sim NID(0, \sigma^2_\upsilon)$ and $\upsilon_0 = 0$. The transition shock to productivity $\eta_t \sim NID(0, \sigma^2_\eta)$. Moreover, individuals are divided into two groups according to their skill levels ι. Normally the skill levels also represent individuals' educational levels. Here, we use $\iota \in \{H, L\}$ to represent high or low skilled individuals, respectively. All individuals maximize their own lifetime utility by choosing the amount of consumption $(c_{i,j})$, labour $(h_{i,j})$, and savings $(a_{i,j})$:

$$u(c_{i,j}, h_{i,j}) + \sum_{s=1}^{J-j+1} \beta^s \prod_{q=1}^{s}(\psi_q)u(c_{i,s+1}, h_{i,s+1}), \tag{2.4}$$

where β is the time discount factor and ψ_q is the survival probability of living to age $j+1$ conditional on being alive at age j.

2.2.2 Technology

Aggregate technology follows a constant return to scale representation modelled by Cobb-Douglas production function:

$$F(K_t, N_t) = A_t K_t^{\alpha} N_t^{1-\alpha}, \tag{2.5}$$

where α is the capital share of the output; K_t is the aggregate capital shock; N_t is the aggregate labour. Firms are maximizing their profit in every period:

$$\Pi_t(K_t, N_t) = Y_t - w_t N_t - (r_t + \delta) K_t.$$

The first order condition gives the optimal choice of the firm setting the wage rate to the value of marginal productivity of labour and rental rate to the value of marginal productivity of capital with the following equations:

$$\begin{aligned} w_t &= A_t(1-\alpha)k_t^{\alpha}, \\ r_t &= A_t \alpha k_t^{\alpha-1} - \delta, \end{aligned} \tag{2.6}$$

where k_t is the capital-labour ratio at time t, and $\delta < 1$ is the depreciation rate of physical capital. The technology parameter A_t is normalized to 1. The constraint of the aggregate resources is given as follows:

$$C_t + K_{t+1} - (1-\delta)K_t + G_t \leq K_t^{\alpha} N_t^{1-\alpha}, \tag{2.7}$$

where C_t is the aggregate consumption, and G_t is the aggregate government expenditure.

2.2.3 Government Policy

The government collects taxes from labour income, capital income, and consumption in order to finance its expenditure G_t. Following Conesa et al. (2009), the individual's taxable labour income is given by

$$y^l_{i,j} \equiv w_t \omega_{i,j} h_{i,j} - 0.5\tau_{ss} \min\{w_t \omega_{i,j} h_{i,j}, \bar{y}\},$$

where $\bar{y}$ is the maximum amount that the individuals' labour income is taxed and τ_{ss} is the payroll tax rate.[7] The capital income is $y^k \equiv r_t(a + beq_t)$. Hence, the amount of total taxes is determined by four components: a non-linear tax schedule $T(\cdot)$ applying to the labour income $y^l_{i,j}$, a flat capital income tax rate τ_k applying to the capital income $y^k_{i,j}$, a flat consumption tax rate τ_c applying to the consumption $c_{i,j}$, and a flat tax rate τ_I applying to the total taxable income $I_{i,j} \equiv y^l_{i,j} + y^k_{i,j}$. The equation that gives the amount of total taxes at age j is given as follows:

$$T_j = T(y^l_{i,j}) + \tau_k(y^k_{i,j}) + \tau_c(c_{i,j}) + \tau_I(I_{i,j}). \tag{2.8}$$

The term τ_I is endogenously determined in the model so that the government budget is balanced.[8] In addition, the government runs a pay-as-you-go (PAYG) social security system. Within this system, the government collects the payroll taxes and redistributes the amount of SS_t to the retired population. The payroll tax that each individual pays is given by $\tau_{ss} \min\{w\omega h, \bar{y}\}$.

2.2.4 Equilibrium Definition

In this section, we define the competitive equilibrium of this model. The state variables are: individual assets a, idiosyncratic productivity ω, and age j. These are jointly represented as $\Omega_t = (j, a_t, \omega_t)$ for the aggregate state of the economy at time t.

Definition 1 *Given a sequence of skill accumulation parameters* $\{\Theta_j\}_{j=20}^{j_r-1}$,[9] *payroll tax rate* $\{\tau_{ss}\}_{t=1}^{\infty}$, *capital income tax rate* $\{\tau_k\}_{t=1}^{\infty}$, *consumption tax rate* $\{\tau_c\}_{t=1}^{\infty}$, *government expenditure* $\{G_t\}_{t=1}^{\infty}$, *social security benefits* $\{SS_t\}_{t=1}^{\infty}$, *and a set of demographic parameters* $\{n, \psi_j\}$, *a tax function* $T : \mathbb{R}_+ \rightarrow \mathbb{R}_+$, *a maximum amount of taxable income for*

[7] Half of the pre-tax labour income that is accounted for social security contribution is paid by the employer, which is not taxed under the current US tax code.

[8] If $\tau_I > 0$, then $y^l_{i,j}$ and $y^k_{i,j}$ are double taxed. If $\tau_I < 0$, individuals are subsidized with a fraction of their gross income.

[9] The Θ sequence only applies to the HCA model.

social security $\bar{y}$, a production plan for the firm (N, K), an age-specific human capital accumulation function $S : \mathbb{R}_+ \times \mathbb{R}_+ \times \mathbb{R}_+ \to \mathbb{R}_+$, and a utility function $U : \mathbb{R}_+ \times \mathbb{R}_+ \to \mathbb{R}_+$, a stationary competitive equilibrium consists of individuals' decision rules $\{c, h\}$ for each state κ, factor prices $\{w, r\}$, accidental bequests beq, and the distribution of individuals $\{\mu(\kappa)\}$ such that the following holds:

1. *The individual maximizes Equation (2.4) given prices $\{w, r\}$, policy $\{T\}$, accidental bequests $\{beq\}$, benefits $\{SS\}$, and idiosyncratic productivity $\{\omega\}$ subject to*

$$\begin{aligned} c + a' =& w\omega h - \tau_{ss} w\omega h + (1+r)(a + beq) \\ & - T[w\omega h - 0.5\tau_{ss}\min\{w\omega h, \bar{y}\}) + r(a + beq)] - \tau_c c \\ & - \tau_I[w\omega h - \tau_{ss} w\omega h + r(a + beq)], \end{aligned} \tag{2.9}$$

for $j \leq j_r$, and

$$\begin{aligned} c + a' =& SS + (1+r)(a + beq) \\ & - T[r(a + beq)] - \tau_c c - \tau_I[r(a + beq)], \end{aligned} \tag{2.10}$$

for $j > j_r$. And at the same time,

$$c \geq 0, 0 \leq h \leq 1, a \geq 0, a_1 = 0.$$

2. *The firm maximizes its profit according to Equation 2.4 where prices w and r satisfy*

$$r = \alpha(\frac{K}{N})^{\alpha-1} - \delta$$

and

$$w = (1-\alpha)(\frac{K}{N})^{\alpha}.$$

3. *The social security policies satisfy*

$$\tau_{ss} = \frac{\sum_{j>j_r} SS\mu(\kappa)}{\sum_{j\leq j_r}\min\{w\omega h, \bar{y}\}\mu(\kappa)}.$$

4. *Accidental bequests are given by*

$$beq = \sum (1-\psi) a' \mu(\kappa).$$

5. *Government balances its budget*

$$G = \sum \tau_k [r(a+beq)]\mu(\kappa) + \sum_{j \le j_r} T[w\omega h - 0.5\tau_{ss} \min\{w\omega h, \bar{y}\})]\mu(\kappa) + \tau_c \sum c\mu(\kappa) + \tau_I \left\{ \sum_{j \le j_r} [w\omega h - 0.5\tau_{ss} \min\{w\omega h, \bar{y}\})]\mu(\kappa) + \sum [r(a+beq)]\mu(\kappa)] \right\}. \tag{2.11}$$

6. *The market clears*

$$K = \sum a\mu(\kappa)$$
$$N = \sum \omega h \mu(\kappa),$$

and

$$\sum c\mu(\kappa) + \sum a'\mu(\kappa) + G = K^\alpha N^{1-\alpha} + (1-\alpha)K.$$

7. *The distribution of $\mu(\kappa)$ is stationary. The law of motion for the distribution of individuals over state space satisfies $\mu(\kappa) = Q_\mu \mu(\kappa)$, where Q_μ is a one-period recursive operator on the distribution.*

2.3 Calibration

We calibrate the model economy to the U.S. economy. Some parameters are taken from external sources such as previous literature and data. Some other parameters are calibrated to match the baseline steady state equilibrium with the empirical data. Table 2.1 shows the external parameters. Table 2.2 shows the calibrated parameters.

2.3.1 Demographics

We assume that individuals start working at age of 20, retire at age 66, and may survive until age 100. The unconditional survival probability ψ_j is determined by the estimation

Table 2.1: External parameters

Parameter	Value	Source
Damographics		
Retire age: j_r	66	By assumption.
Max age: J	100	By assumption.
Sur. prob: ψ_j	$\{\psi\}_{j=1}^{J}$	Bell & Miller (2005)
Pop. growth: n	1.1%	Peterman (2016)
Firm parameters		
Capital share: α	0.36	Peterman (2016)
Depreciation rate: δ	8.33%	Peterman (2016)
Technology: A	1	Normalization
Productivity parameters		
Persistence shock: σ_{υ}^2	0.017	Kaplan (2012)
Persistence: ρ	0.958	Kaplan (2012)
Permanent shock: σ_{ζ}^2	0.065	Kaplan (2012)
Transitory shock: σ_{η}^2	0.081	Kaplan (2012)
Government parameters		
Payroll tax: τ_{ss}	0.124	Conesa et al.(2009)
Avg. tax rate: λ_0	0.911	Guner et al.(2016)
Tax progressivity: λ_1	0.053	Guner et al.(2016)
Human capital parameters		
Φ_1	0.407	Chang et al.(2002)
Φ_2	0.326	Chang et al.(2002)

Table 2.2: Calibration parameters

Parameter	non HCA	HCA	Target
Discount factor: β	0.977	0.982	$\frac{K}{Y} = 2.7$
Risk aversion: σ_1	2	2	IES=0.5
Frisch elasticity: σ_2	4.0	4.3	Frisch $= \frac{1}{2}$
Value of leisure: χ	0.83	1.5	Avg.$h_j = \frac{1}{3}$

provided by Bell and Miller (2005). The population growth rate is set to 1.1 percent.

2.3.2 Preferences and Endowments

The instantaneous utility function we use is given as follows:

$$u(c_t, 1-h_t) = \frac{c_t^{1-\sigma_1}}{1-\sigma_1} + \chi\frac{(1-h_t)^{1-\sigma_2}}{1-\sigma_2},$$

where χ represents the disutility of working; σ_1 and σ_2 are the risk aversion parameters. We calibrate the discount factor β to match the target capital-output ratio at 2.7 and set the risk aversion parameter $\sigma_1 = 2$ following Conesa et al. (2009). We set $\sigma_2 = 4$ in the non HCA model and $\sigma_2 = 4.3$ in the HCA model in order to obtain an average Frisch elasticity of labour supply as $\frac{1}{2}$ following Peterman (2016) in both models.[10]

2.3.3 Idiosyncratic Labour Productivity

We assume that each individual is endowed with one unit of productive time that can be used to provide labour $(h_{i,j})$ and leisure $(1-h_{i,j})$. The idiosyncratic labour productivity $\omega_{i,j}$ depends on the age j, age-specific human capital ε, ability ζ, skill level ι, and an idiosyncratic shock η. The idiosyncratic shock η takes 7 values for each skill-level of individuals. The first 5 shocks, $\eta_{\iota,1}, \eta_{\iota,2}, ..., \eta_{\iota,5}$ are called the 'normal' shocks which are generated by a standard AR(1) process. The last two shocks, $\eta_{\iota,6}, \eta_{\iota,7}$ are known as the very high productivity shocks, called as 'lucky states', which are not captured by any observations in the PSID data (Kindermann and Krueger (2020)). In order to capture the effect of very high earnings and generate a closer wealth Gini for the US economy, we transfer the 5×5 Markov transition matrix to 7×7 following Kindermann and Krueger

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$$\text{Frisch} = \begin{cases} \frac{U_h U_{cc}}{h[U_{ch}^2 - U_{cc}U_{hh}]} & \text{in non HCA model,} \\ \frac{U_h U_{cc}}{h[U_{ch}^2 - U_{cc}U_{hh} + \frac{h'w'}{rws}(s_h'(U_{ch}^2 - U_{cc}U_{hh}) - U_{cc}U_h s_{hh}')]} & \text{in HCA model.} \end{cases}$$

Notice that the Frisch elasticity is constant in the non HCA model. On the contrary, it is increasing in the HCA model. Thus, when we do calibration for the HCA model, we use the average Frisch elasticity as the target.

(2020) as follows:

$$\pi_\iota = \begin{Bmatrix} \pi_{11,\iota}(1-\pi_{6,\iota}) & ... & \pi_{13,\iota}(1-\pi_{6,\iota}) & ... & \pi_{15,\iota}(1-\pi_{6,\iota}) & \pi_{6,\iota} & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \pi_{51,\iota}(1-\pi_{6,\iota}) & ... & \pi_{53,\iota}(1-\pi_{6,\iota}) & ... & \pi_{55,\iota}(1-\pi_{6,\iota}) & \pi_{6,\iota} & 0 \\ 0 & ... & 1-\pi_{66,\iota}-\pi_{67,\iota} & ... & 0 & \pi_{66,\iota} & \pi_{67,\iota} \\ 0 & ... & 0 & ... & 0 & 1-\pi_{77,\iota} & \pi_{77,\iota} \end{Bmatrix}$$

For each state $\{\eta_{\iota,1}, \eta_{\iota,2}, ..., \eta_{\iota,5}\}$, there is a small probability to move to a higher state $\eta_{\iota,6}$. In order to move to the highest shock $\eta_{\iota,7}$, the individual should first hit at $\eta_{\iota,6}$. These 'lucky states' are temporary. If a bad shock hits, the individual will stay at state $\eta_{\iota,3}$ for sure. Apart from these, the persistent, permanent, and transitory idiosyncratic labour productivity shocks are calibrated following Kaplan (2012). These shocks are normally distributed with zero mean, and their variances are given as following: $\sigma_\zeta^2 = 0.065, \sigma_\upsilon^2 = 0.017$, and $\sigma_\eta^2 = 0.081$ respectively. The persistent parameter is $\rho = 0.958$.

2.3.4 Government Policy

We use the income tax function introduced by Benabou (2002) to capture the progressive structure of the U.S. income tax system. The functional form is given as follows:

$$T_t(y_t) = y_t - \lambda_0 (y_t)^{1-\lambda_1}. \tag{2.12}$$

The parameter λ_0 captures the average tax rate, and λ_1 governs the curvature of the tax function, i.e. the progressivity of the system. Notice $1 - \lambda_1$ measures the elasticity of post-tax to pre-tax income (Heathcote et al. (2017)). Guner et al. (2016) estimate that $\lambda_0 = 0.911$ and $\lambda_1 = 0.053$ by using the U.S. data.

2.4 Results

2.4.1 Benchmark Results

In this section, we show the benchmark results of both the HCA and the non HCA models. These two benchmarks are calibrated separately to meet the target moments, as stated in

Section 2.3 (see Table 2.2). Table 2.3 demonstrates the aggregate economic variables under both models. Although there is a slight difference between the two models, the benchmark results are relatively close to each other. These two models are used as baseline models for later experiments. In addition, both models generate the four Gini coefficients close

Table 2.3: Aggregate economic variables

	non HCA	HCA
Aggregate		
Y	1.19	1.17
K	3.17	3.24
N	0.68	0.68
Avg. hours	0.33	0.30
w	0.93	0.91
r	0.052	0.046
beq	0.040	0.039
Average tax rate		
Labour	0.1259	0.1232
Capital	0.0976	0.0848
Ratio	1.2897	1.4539
Marginal tax rate		
Labour	0.1723	0.1697
Capital	0.1455	0.1333
Ratio	1.1841	1.2734

to what was observed in the U.S. data (see Table 2.4). Both models generate the labour income Gini, consumption Gini, and disposable income Gini coefficients close to what we observe in the U.S. data (see Table 2.4). It is challenging to generate the wealth Gini coefficients close to that of the data. To get realistic wealth Gini coefficients, we followed Kindermann and Krueger (2020). Hence, we generate wealth Gini coefficients as 0.70 and 0.77 in the HCA and the non HCA models, respectively. These coefficients are closer to that of the actual data (0.80) compared to 0.63 reported in Guner et al. (2016) and 0.60 reported in Ventura (1999).

Next, we compare both models' benchmark results with the actual data by plotting the life-cycle profiles for both models. Figure 2.1 shows the results of the average unit of time individuals spend on working, the average consumption, the median savings, and the average labour income for both models compared to the actual data. The red line, blue line, and dashed line represent the trends in the HCA model, non HCA model, and the

Table 2.4: Gini coefficients

	Data	non HCA Model	HCA Model
labour income	0.55	0.53	0.52
consumption	0.34	0.33	0.31
disposable income	0.40	0.39	0.36
wealth	0.80	0.77	0.70

Notes: The U.S. data is based on the data for 1999-2013 taken from Fisher et al. (2016)

actual data, respectively.[11]

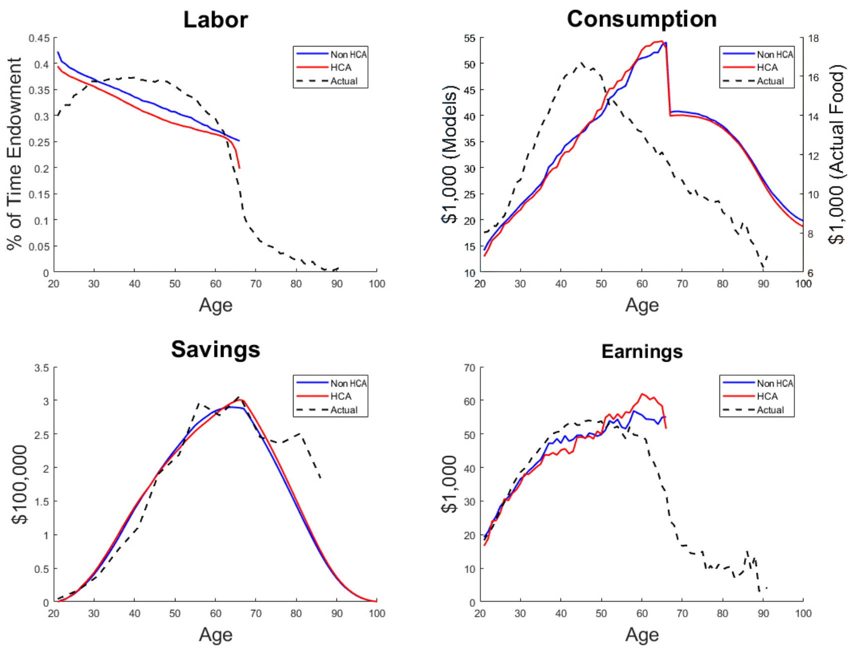

Figure 2.1: Actual, non HCA and HCA life-cycle profiles

In the data, labour supply has a hump shape, while the models generate a decreasing trend in individuals' working hours with a higher starting point. The reason is that young individuals need to consume and accumulate precautionary savings since they enter the model with no assets. As the workers accumulate more experience and wealth, they decrease their working hours overtime. While in reality, individuals are born with support from parents or inheritance. Apart from these, they also have the means to borrow for consumption. Hence, young individuals' labour supply is lower than that generated by the models. Middle-aged workers, on the other hand, may need to raise children and care for their parents. Hence, they tend to work more. This is why we observe higher labour supply

[11]The labour supply, labour income, and consumption are compared to that of the data in Peterman (2016).

between the age of 30 and 60 in the data. Moreover, the labour supply generated in the HCA model is slightly lower than the non HCA model. Due to the existence of endogenous human capital accumulation, working individuals accumulate higher productivity and hence work less in the HCA model.

The consumption plots have hump shapes for both the models and the data. Generally, the consumption profiles generated by the models are much higher than the consumption in the data since the PSID data only reports the expenditures on food, while the models generate all consumption. Moreover, we can observe that the consumption profile in the data peaks at an earlier age (around 45) while the models' consumption peaks at the age of 66, right before individuals' retirements. Again, since the consumption profile in the data plots the actual food expenditure, it is natural that individuals reduce food consumption when they are getting old. Hence, the consumption profile in the data keeps decreasing after the age of 45. The models generate the consumption profile that includes food consumption and other nondurable consumption as well.[12] Individuals consume as much as they can before retirement. Then, at the age of 66, there is a sudden drop as the individuals retire in both HCA and non HCA models. Overall, the consumption profile we generated is similar to that generated in the previous literature (see Conesa et al. (2009)).

The savings show similar trends in the models and the data. All these plots have hump shapes and peak at around the age of 66. Intuitively, in the model, the savings increase as the individuals accumulate more assets while working and decreases as the individuals retire after the age of 66. There is a small difference between the models and the data during the age of 50 and 60, where the savings data is higher than that generated by the models. This might be due to gifts or inheritance received from parents in reality. After the age of 70, the actual savings remain at the same level and even increase a little due to altruistic reasons most likely. Then, after the age of 85, the actual savings start to decrease as in the savings in the models.

The labour income profiles show similar trends in all three plots before the age of 55. Instead of a hump shape as in the actual labour income, both models generate increasing trends in the labour income between the age of 56 and 66. In the model, all individuals are forced to work until the age of 66 unless they die before. In reality, individuals at the age of around 60, decrease their working hours, shifting from full-time to part-time workings.

[12]Other nondurable consumption may include clothing, shoes, fuel, cigarettes, and even luxury goods.

We also observe a decrease in labour income in the HCA model, which is associated with a decrease in the labour supply between the age of 65 and 66.

Overall, both of the models are doing a relatively good job in generating the labour supply, labour income, consumption, and savings profiles close to what is observed in the data. The shape of plots of labour supply and capital savings is similar to the ones in Peterman (2016). But we have a better fit in the savings and also the young age labour incomes. The biggest difference between our model and Peterman (2016) is the consumption profile. We capture the drop in consumption before retirement better.

2.4.2 Proportional Consumption Tax Experiments

In this section, we analyze the implication of increasing the proportional consumption tax rate on economic aggregates, social welfare, and inequalities. In particular, we increase the consumption tax rate from 5% to 95% in 10% increments in both models. We keep all other parameters and the government expenditure the same as in the benchmarks for both models.

Distributional Effects

In Figures 2.2 and 2.3, we show the changes in savings, transfers, consumption, interest rate, labour supply, wage, and output when there is an increase in the consumption tax rates for both the HCA (red line) and the non HCA (blue line) models. More specifically, we observe that an increase in the capital stock in both models. When the consumption tax rate is smaller than 55 percent, the changes are almost the same. While the consumption tax rate is greater, the capital stock in the HCA model increases much faster than the non HCA model to a higher level. Similarly, the aggregate transfer (accidental bequest plus the social security transfer) in the HCA model and the non HCA model separate from each other when the consumption tax rate increases to 55 percent. Both models generate increasing transfers when the consumption tax rate is lower than 65 percent. After the increasing trend, both transfers start to decrease. In the HCA model, the transfers are decreasing slower and remain at a higher level than those of the non HCA transfers. The aggregate consumption in both models has hump shapes. There is only a slight difference between the two plots. When the consumption tax rate is relatively

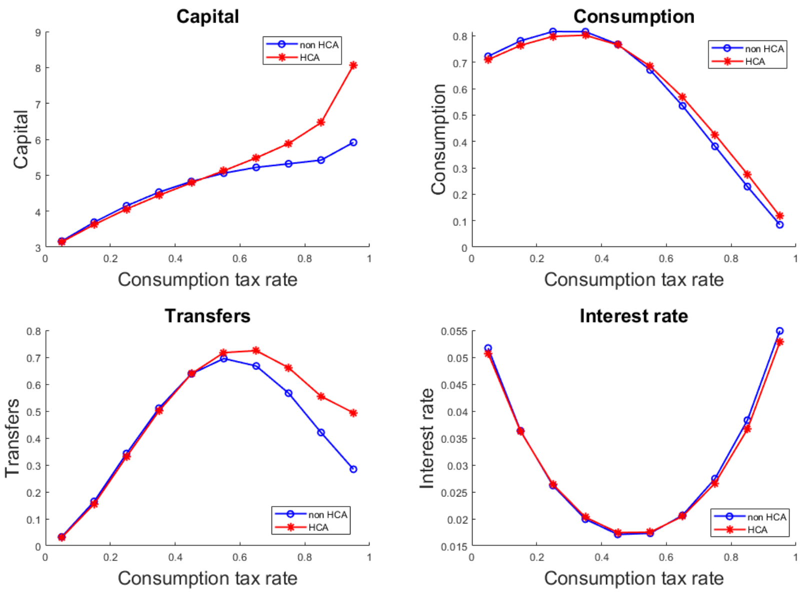

Figure 2.2: Capital, consumption, transfer, and interest rate. **Note**: The figure plots the aggregate components corresponding to different consumption tax rates in each model.

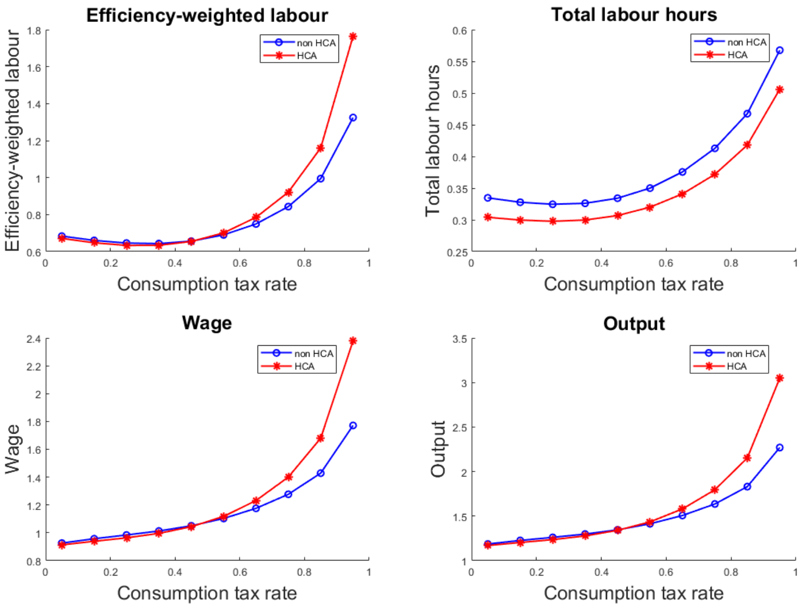

Figure 2.3: Labour supply, working hours, wage rate, and output. **Note**: The figure plots the corresponding aggregate components in each model.

low, the HCA consumption is lower than the non HCA consumption. While when the consumption tax rate is relatively higher, the HCA consumption is greater than the non HCA consumption. In both HCA and non HCA models, the interest rate first decreases and then increases with very similar values. The cut point is still 55 percent.[13]

The aggregate labour supply (upper-left plot of Figure 2.3), the total working hours, average income, and output increase as the consumption tax rate increases. The figure shows that the working hours do not change much when the consumption tax rate is lower than 50 percent, but increase substantially when the consumption tax rate is greater than 55 percent. Intuitively, this is due to the fact that the individuals have to work harder (more hours) to compensate for the large increase in the consumption tax rate. The working hours also show that, in the HCA model, individuals work less hours than in the non HCA model. But the slopes of the working hours are the same. This means that the endogenous human capital accumulation reduces the total hours working but does not affect the working hours' response to the change in consumption tax rates. Yet, by observing the aggregate labour supply, the endogenous human capital accumulation does affect the responses of aggregate labour supply to the consumption tax rates when it is lower than 55 percent. This is consistent with the changes in the average income.

In Figure 2.4, we show that the capital-output ratio, transfer-output ratio, and the capital-labour ratio have all hump shapes and peak at 55 percent. The plots are very close to each other in the HCA model and the non HCA model. In particular, when the consumption tax rate is higher than 55 percent, all three ratios start to decrease. As a result, the interest rates in Figure 2.2 are U-shaped and peak at around 55 percent in HCA and non HCA models. Since we observe increases in capital stock, labour supply and output at the same time when the consumption tax rate is greater than 55 percent (see Figures 2.2 and 2.3), the decrease in capital-output ratio and capital-labour ratio suggests that the output and the labour supply are increasing faster than the capital stock. The decrease in the transfer-output ratio comes from a joint effect of the decrease in aggregate transfer and the increase in output. From these figures, we see that the three ratios in the HCA model are slightly greater than the non HCA model when the consumption tax rate

[13] when consumption tax rates are low, the effect of the change in consumption tax rate is limited. The reformed economy does not diverse much from the baseline. And since the baselines are calibrated to the same targets in both models, the results do not differ much. On the other hand, when the consumption tax rate increases large enough, the effects are larger and distinguish more from the baseline.

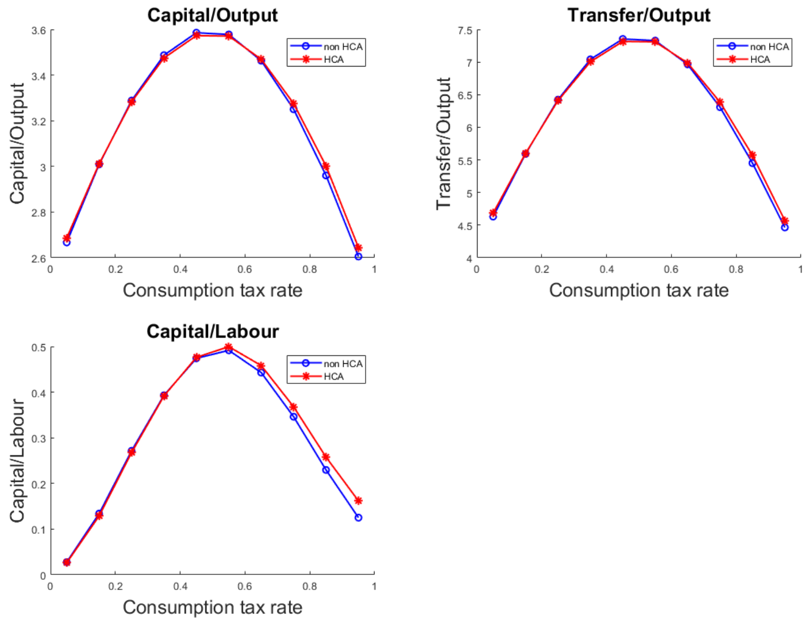

Figure 2.4: Capital output ratio, capital labour ratio, and capital labour ratio. **Note**: The figure plots the corresponding ratios in each model.

is greater than 55 percent. Intuitively, with the presence of endogenous human capital accumulation, individuals accumulate higher labour productivity much faster. This, in turn, generates a faster increase in production and the aggregate labour supply, average income, and capital stock.

In sum, as the consumption tax rate increases, individuals have a higher incentive to work, save and invest. Hence the labour supply, aggregate savings, and output are increasing. The consumption first increases and then drops while the interest rate first decreases and then increases with the cut point at 55 percent. These results are consistent with Kitao (2011) and Ventura (1999). To be more specific, Kitao (2011) finds that when the consumption tax rate increases from 5 percent to 45 percent, the capital stock, labour supply, consumption, and wage increase; while the interest rate decreases. Ventura (1999) also finds increases in capital stock, labour supply, and savings rate when replacing the income tax system with a flat consumption tax.[14] Our results substantially differ from those of Nakajima and Takahashi (2020). Nakajima and Takahashi (2020) employ an infinite horizon model and conduct their analysis assuming divisible and non-divisible labour supply, respectively. Our results can be compared to their results when the labour supply is divisible. Nakajima and Takahashi (2020) find that an increase in the consumption

[14] The income tax system includes the federal income, corporate income, and capital income taxation.

tax rate decreases the labour supply, output, and capital-output ratio. Correia (2010) suggests that an increase in a flat consumption tax reform increases labour efficiency.[15] Yet, we observe an opposite result when the consumption tax rate is lower than 30 percent. Notice that Correia (2010) increases the consumption tax rate while decreasing the labour income and capital income tax rates at the same time until the labour income and capital income taxes are fully replaced. In contrast to Ventura (1999), Correia (2010), Kitao (2011), and Nakajima and Takahashi (2020), we incorporate endogenous human capital accumulation as well. In the HCA model, the endogenous human capital accumulates in each period and affects the individuals' labour productivity, which further affects their average income, output, and transfers. These, in turn, affects the individuals' decisions on working hours, savings, and consumption. The economic aggregates in HCA model are hence more sensitive to the change of consumption tax rate, especially when the consumption tax rate is relatively high. Therefore, we observe higher slopes in HCA model than non HCA model when the consumption tax rate is higher than 55 percent.

Welfare Effects and Inequalities

In this subsection, we analyze the implications of increasing consumption tax rates on welfare and inequalities in both HCA and non HCA models. We use the consumption equivalent variation (CEV) as a welfare measure, which is defined as the constant percentage change in nondurable consumption that equates the discounted sum of lifetime utility in the baseline economy compared to the reformed economy. The CEV function we use is as follows:

$$CEV = (\frac{V_e}{V_b})^{\frac{1}{1-\sigma_1}} - 1,$$

where V_e represents the value function of the counterfactual experiments and V_b represents the value function of the baseline model. We find that increasing the consumption tax leads to a hump shape trend in CEVs. In Figure 2.5, when the consumption tax rate is less than 45 percent, both HCA and non HCA models generate welfare gains. This increasing trend in CEV is consistent with that of Kitao (2011). When the consumption tax rate is higher than 55 percent, a notable welfare loss is observed as the consumption tax rate increases. Such hump shape in the CEV plot is consistent with the hump shape

[15] Correia (2010) increases the consumption tax rate from 0% to 29%.

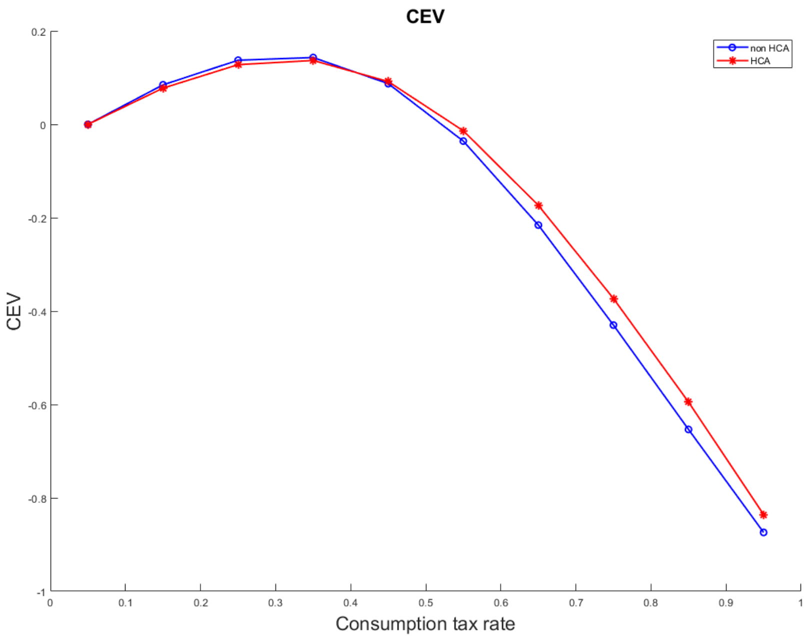

Figure 2.5: Social welfare as measured by % change in CEV.

of consumption in Figure 2.2. In addition, with an increase in working hours, disutility in working also contributes to the decrease in the CEV. A comparison between the HCA and the non HCA models shows a greater value of CEV in the HCA model. In other words, when the consumption tax rate is higher than 55 percent, the HCA model generates relatively fewer welfare losses. This is because, with the presence of endogenous human capital accumulation, HCA individuals work fewer hours since they accumulate higher productivity through working than the non HCA individuals. In this way, they have more leisure and hence higher utilities compared to the non HCA individuals.

Now, we look at the effects of a change in the consumption tax rate on the inequalities measured by wealth Gini, consumption Gini, labour income Gini, and disposable income Gini coefficients. In Figure 2.6, we show that when the proportional consumption tax rate increases, the wealth Gini is generally decreasing; the consumption Gini is increasing; the earnings (labour income) Gini first decreases and then increases; and the disposable income Gini first increases and then decreases. This result contrasts with that of Nakajima and Takahashi (2020), where the wealth Gini and labour income Gini are generally increasing while the consumption Gini and the disposable income Gini are decreasing. In our model, in order to have more precautionary savings against higher consumption tax rates, low income individuals work more and consume less. On the other hand, high income individuals do not

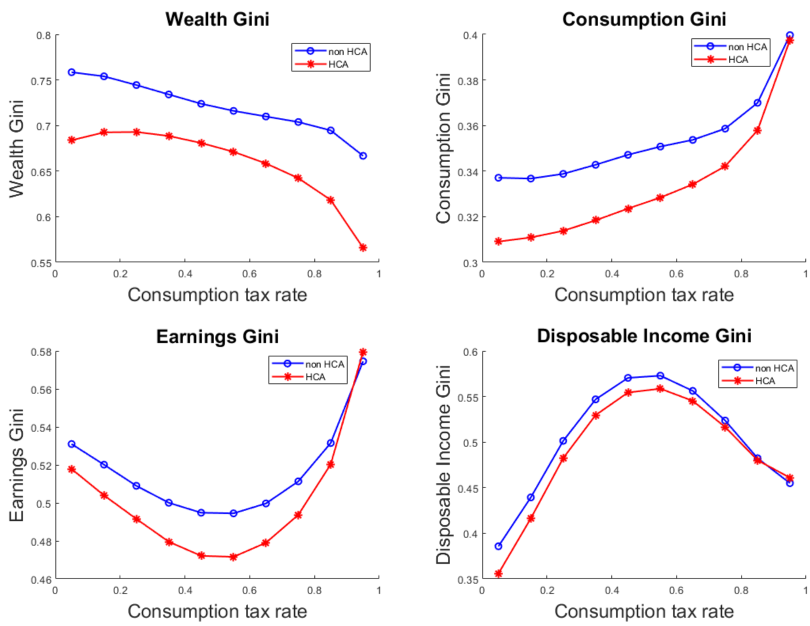

Figure 2.6: Gini coefficients. **Note**: The Gini coefficients of wealth, consumption, labour income, and disposable income in each model.

worry as much as low income individuals about their future consumption. The high income individuals may reduce their consumption but not as much as the low income individuals do. Hence, the high income individuals have fewer increases in savings (compared to the low income individuals) when the consumption tax rate increases. As a result, the wealth Gini decreases while the consumption Gini increases. In other words, the wealth inequity is reduced while the consumption inequality is enlarged. As the consumption tax rate further increases, both the high income and low income individuals tend to work more. Moreover, when the consumption tax rate increases to 55 percent, the low income households work more hours, but the high income households might not change their working hours much.[16] Hence, the labour income Gini decreases. Taking the increase in the consumption tax rate, the change in individuals' working choices,[17] the progressive labour income taxation system, and the transfers individuals get into account, the disposable income of low income individuals increase slower than their labour income.[18] But the disposable income of high income individuals does not change much. Hence, the difference between the low income individuals' disposable income and the high income individuals' disposable income become

[16]The high income households may even work less due to the increase in the efficiency wage rates when consumption tax rate is relatively low.

[17]The individuals' working choices refer to that low income individuals work more but high income individuals do not change their working hours much when consumption tax rate is relatively low.

[18]The disposable income is the after-tax income plus any transfers individuals get.

larger. As a result, the disposable income Gini increases when the consumption tax rate is lower than 55 percent. On the contrary, when the consumption tax rate is greater than 55 percent, both low income individuals and high income individuals substantially increase their working hours. Due to the substantial increase in working hours, high income individuals who experience higher labour productivity shocks than low income individuals would also experience a higher increase in their labour income. Thus, the earnings Gini is increasing when the consumption tax rate is larger. However, high income individuals face higher marginal tax rates than the low income individuals. Hence, the increase in the consumption tax rates lowers the disposable income inequality. In general, we observe the opposite trends between the earnings Gini and the disposable income Gini. This result is consistent with that of Nakajima and Takahashi (2020), where the earnings Gini and the disposable income Gini have the opposite trends as well. The relatively low value of Gini coefficient in the HCA model (red line) comes from the low benchmark Ginis. Hence, we pay more attention to the relative change (slope) in Gini coefficients when comparing the HCA and non HCA models. Comparing the HCA and the non HCA models, the change of inequalities are more sensitive in the HCA model (the red line's slopes are higher). The endogenous human capital accumulation helps individuals gain more experience from working and get higher productivity and hence higher labour income. This, in turn, affects the individuals' savings and consumption decisions. In other words, the existence of endogenous human capital accumulation enlarges the response of the economic aggregates to any changes. Therefore, we observe higher relative changes in the HCA model.

In sum, increasing the consumption tax rates generates welfare gains when consumption tax rates are less than 55 percent but generate welfare losses when consumption tax rates are higher. Wealth inequalities are reduced with the increase in consumption tax rates, but consumption inequalities are increased. The HCA model is more sensitive to the changes (has a higher slope) in consumption tax rates due to the existence of human capital accumulation.

2.4.3 Progressive Consumption Tax Experiments

In this section, we replace the proportional consumption tax rate τ_c with a progressive consumption tax rate function $T_c(c)$ (see equation 2.13) and conduct two sets of counterfactual experiments. In the reformed consumption tax rate function, we have two thresholds, c_m and c_h. Hence, we have three brackets, namely the lower bracket $[0, c_m)$, the middle bracket $[c_m, c_h)$, and the upper bracket $[c_h, \infty)$. In the lower bracket, we set $\tau_c = 0$ as the consumption tax rate. The threshold c_m determines a level of a minimum requirement for consumption. In the middle and upper bracket, we set τ_{c_1} and τ_{c_2} as the proportional consumption tax rates, respectively. The higher threshold c_h defines the lower bound of the upper bracket as where luxuries are taxed. To be more specific, the progressive consumption tax rate function we use is given as follows:

$$T_c(c) = \begin{cases} 0 & \text{if} \quad c < c_m \\ \tau_{c_1} & \text{if} \quad c_m \leq c < c_h \\ \tau_{c_2} & \text{if} \quad c \geq c_h, \end{cases} \tag{2.13}$$

where $\tau_{c_1} \leq \tau_{c_2}$.

Our progressive consumption tax related counterfactual experiments can be separated into two groups. In the first group of our experiments, we keep the thresholds ($c_m = 0.3$ and $c_h = 0.9$) unchanged and conduct $9(= 3 \times 3)$ experiments, where we choose τ_{c_1} from $\{0.03, 0.04, 0.05\}$ and τ_{c_2} from $\{0.05, 0.10, 0.15\}$ for both the HCA and the non HCA models. In the second group of our experiments, we omit c_h by setting $\tau_{c_1} = \tau_{c_2} = 0.05$ and conduct 3 experiments where c_m is chosen from $\{0.3, 0.5, 0.7\}$ for each model (see Tables 2.7 (HCA model) and 2.8 (non HCA model)).

Here, we present three experiments for each model setting when $\tau_{c_1} = 0.05$ and $\tau_{c_2} \in \{0.05, 0.10, 0.15\}$ (see Tables 2.5 and 2.6). We show that incorporating a progressive consumption tax regime by allowing a tax free bracket (see the comparison of the first two columns in Tables 2.5 and 2.6) generates a decrease in output, capital stock, labour supply, average working hours, wage rate, bequest, social welfare, and wealth inequality. Yet, we observe an increase in consumption inequality. Low income individuals have less incentive to work hard when a tax free bracket for consumption is introduced. As a

Table 2.5: Progressive consumption tax reform

HCA	Baseline	0.05, 0.05	% change	0.05, 0.10	% change	0.05, 0.15	% change
Aggregate							
Y	1.17	1.17	-0.2%	1.17	-0.2%	1.17	-0.1%
K	3.14	3.13	-0.3%	3.17	+1.0%	3.21	+2.0%
N	0.67	0.67	-0.1%	0.67	-0.8%	0.66	-1.3%
Avg. hours	0.30	0.30	-0.5%	0.30	-1.0%	0.30	-1.5%
w	0.91	0.91	-0.3%	0.91	-0.2%	0.91	-0.1%
r	0.051	0.051	+0.4%	0.049	-2.9%	0.048	-5.4%
beq	0.037	0.037	-0.2%	0.038	+0.1%	0.038	+0.7%
CEV		-0.37%		1.64%		3.31%	
Gini							
Consumption	0.31	0.31	+0.3%	0.31	-2.0%	0.31	-4.2%
Wealth	0.69	0.68	-0.1%	0.69	+0.4%	0.69	+0.5%
Average tax rate							
Labour	0.1245	0.1246		0.1248		0.1252	
Capital	0.0861	0.0862		0.0859		0.0858	
Ratio	1.4450	1.4457		1.4525		1.4598	
Marginal tax rate							
Labour	0.1709	0.1710		0.1712		0.1716	
Capital	0.1346	0.1346		0.1344		0.1342	
Ratio	1.2697	1.2702		1.2740		1.2783	

Note: $\tau_c = 0.05$ in baseline; the experiment heading pair are τ_{c_1} and τ_{c_2}, respectively.

Table 2.6: Progressive consumption tax reform (cont.)

non HCA	Baseline	0.05, 0.05	% change	0.05, 0.10	% change	0.05, 0.15	% change
Aggregate							
Y	1.18	1.18	-0.2%	1.19	+0.1%	1.19	+0.5%
K	3.17	3.15	-0.4%	3.23	+2.0%	3.29	+3.9%
N	0.68	0.68	-0.1%	0.68	-0.9%	0.67	-1.4%
Avg. hours	0.33	0.33	-0.8%	0.33	-1.7%	0.33	-2.5%
w	0.93	0.92	-0.2%	0.93	+0.1%	0.93	+0.5%
r	0.052	0.052	+0.5%	0.049	-4.7%	0.047	-8.6%
beq	0.040	0.040	-0.4%	0.041	+0.7%	0.041	+1.9%
CEV		-0.07%		2.68%		5.12%	
Gini							
Consumption	0.34	0.34	+0.3%	0.33	-2.4%	0.32	-4.9%
Wealth	0.76	0.76	-0.05%	0.76	+0.1%	0.76	+0.2%
Average tax rate							
Labour	0.1259	0.1261		0.1263		0.1266	
Capital	0.0976	0.0977		0.0970		0.0966	
Ratio	1.2897	1.2916		1.3015		1.3097	
Marginal tax rate							
Labour	0.1723	0.1724		0.1726		0.1729	
Capital	0.1455	0.1455		0.1449		0.1445	
Ratio	1.1841	1.1853		1.1912		1.1961	

Note: $\tau_c = 0.05$ in baseline; the experiment heading pair are τ_{c_1} and τ_{c_2}, respectively.

result, output, capital stock, labour supply, and average working hours decrease. Since the percentage decrease in labour supply is smaller than the percentage decrease in capital stock, the capital-labour ratio decreases. We observe a slight welfare loss as indicated by a small decrease in CEV. This is probably caused by the individuals who normally consume around the amount of the threshold we set. With the presence of the tax free bracket, these individuals can slightly reduce their consumption to avoid being taxed. The results also show a slight increase in consumption Gini coefficient and a slight decrease in wealth Gini coefficient. The intuition is the same; individuals in the baseline who consume around the lower threshold have an incentive to decrease their amount of consumption below the threshold. In this way, consumption inequalities are enlarged but in a very limited amount. Similarly, these individuals save more. Hence, a slightly lower wealth inequality is generated.

In addition, by keeping $\tau_{c_1} = 0.05$ and increasing the value of τ_{c_2}, we can analyze the implications of an increase in the progressivity of this consumption tax system.[19] Such increase in τ_{c_2} increases output, capital stock, wage rate, bequest, and social welfare. On the other hand, it decreases labour supply, working hours, and interest rate. In terms of the trend, both HCA and non HCA models generate the results in the same direction (see Tables 2.5 and 2.6). Since we observe an increase in capital and decrease in labour supply, we have an increasing capital-labour ratio. Hence, it is reasonable to observe an increasing trend of wage rate and decreasing trend of interest rate. Increasing the progressivity by increasing the τ_{c_2} makes the higher level of consumption more expensive. Individuals who are consuming the amount around the upper threshold have more incentive to consume less and save more. These individuals will have less incentive to work more. On the other hand, individuals who continue with high consumption will work more. In terms of social welfare, there is a trade off between consumption and leisure. The increasing trend of CEV shows that the utility gain through the increase in leisure dominates the utility loss through the decrease in consumption. Moreover, when the progressivity of consumption tax increases, the low consumption individuals will consume more and save less. High consumption individuals reduce their consumption and save more. Hence, the consumption inequality is reduced, but wealth inequality is increased. Our results support Mankiw

[19]Since we observe similar results when we keep τ_{c_2} unchanged while increase τ_{c_1}, we omit the results here and show them in the appendix (see Tables B.2 to B.4 (HCA model) and B.5 to B.7 (non HCA model)).

(2015), which states that a progressive consumption tax is a good way of pursuing equality. Intuitively, a progressive consumption tax could lessen the consumption burden for low income individuals. With the same amount of labour income, they could consume more. In this way, it is able to reduce the consumption inequality. When low income individuals choose to consume more, they have less remaining income to save. Hence, an increase in the wealth inequality is observed.

Table 2.7: Progressive consumption tax reform (cont.)

HCA	Baseline	$c_m = 0.3$	% change	$c_m = 0.5$	% change	$c_m = 0.7$	% change
Aggregate							
Y	1.17	1.17	-0.2%	1.16	-1.2%	1.15	-1.6%
K	3.14	3.13	-0.3%	3.03	-3.5%	2.95	-6.1%
N	0.67	0.67	-0.1%	0.67	+0.2%	0.68	+1.1%
Avg. hours	0.30	0.30	-0.5%	0.30	-0.6%	0.30	-0.1%
w	0.91	0.91	-0.3%	0.90	-1.2%	0.90	-1.6%
r	0.051	0.051	+0.4%	0.054	+6.9%	0.057	+12.7%
beq	0.037	0.037	-0.2%	0.036	-5.2%	0.034	-8.3%
CEV		-0.37%		-1.02%		-2.07%	
Gini							
Consumption	0.31	0.31	+0.3%	0.30	-1.3%	0.30	-2.4%
Wealth	0.69	0.68	-0.1%	0.70	+1.9%	0.69	+0.2%
Average tax rate							
Labour	0.1245	0.1246		0.1252		0.1258	
Capital	0.0861	0.0862		0.0877		0.0874	
Ratio	1.4450	1.4457		1.4278		1.4392	
Marginal tax rate							
Labour	0.1709	0.1710		0.1716		0.1721	
Capital	0.1346	0.1346		0.1361		0.1358	
Ratio	1.2697	1.2702		1.2611		1.2678	

Our second group of progressive consumption tax reforms are done by setting three different values of lower thresholds c_m in both HCA and non HCA models. We omit the upper threshold c_h by setting $\tau_{c_1} = \tau_{c_2} = 0.05$. In Tables 2.7 (HCA model) and 2.8 (non HCA model), we observe that increasing the threshold creates a decreasing trend in output, capital stock, wage rate, bequest, social welfare, and consumption inequality. On the contrary, there is an increasing trend in labour supply, interest rate, and wealth inequality. The decrease in capital and increase in labour supply suggest a decrease in the capital-labour ratio. Hence, the wage rate is decreasing while the interest rate is increasing. When the threshold increases, middle consumption individuals have more incentive to consume. Individuals who consume around the threshold prefer to consume less to avoid paying high consumption taxes. The changes in consumption are determined by the relative amount of consumption increased by the middle consumption individuals

Table 2.8: Progressive consumption tax reform (cont.)

non HCA	Baseline	$c_m = 0.3$	% change	$c_m = 0.5$	% change	$c_m = 0.7$	% change
Aggregate							
Y	1.18	1.18	-0.2%	1.17	-1.3%	1.17	-1.7%
K	3.17	3.15	-0.4%	3.04	-4.1%	2.96	-6.6%
N	0.68	0.68	-0.1%	0.69	+0.3%	0.69	+1.1%
Avg. hours	0.33	0.33	-0.8%	0.33	-0.5%	0.34	+0.2%
w	0.93	0.92	-0.2%	0.91	-1.3%	0.91	-1.7%
r	0.052	0.052	+0.5%	0.056	+7.6%	0.059	+13.5%
beq	0.040	0.040	-0.4%	0.038	-5.0%	0.037	-6.9%
CEV		-0.07%		-0.82%		-2.01%	
Gini							
Consumption	0.34	0.34	+0.3%	0.33	-1.4%	0.33	-2.2%
Wealth	0.76	0.76	-0.05%	0.77	+1.8%	0.76	+0.7%
Average tax rate							
Labour	0.1259	0.1261		0.1264		0.1265	
Capital	0.0976	0.0977		0.0999		0.0999	
Ratio	1.2897	1.2916		1.2652		1.2670	
Marginal tax rate							
Labour	0.1723	0.1724		0.1727		0.1728	
Capital	0.1455	0.1455		0.1476		0.1476	
Ratio	1.1841	1.1853		1.1699		1.1711	

and the consumption reduced by the individuals who consume around the threshold level. The results show that the disutility generated by the increase in working hours is the main reason for the social welfare losses. As more individuals are free of consumption taxes, there is no doubt the consumption inequality decreases as low consumption individuals consume more. On the other hand, the wealth inequality increases since low and middle consumption individuals save less.

2.5 Conclusion

In this paper, we study the implications of an increase in consumption tax rates and a progressive consumption tax system with and without the presence of endogenous human capital accumulation in an overlapping generation model on economic aggregates, social welfare, and inequalities. Our baseline model captures important features in the U.S. economy such as consumption, savings, labour income, and inequalities.

Our results from increasing the consumption tax rate show that there is a positive effect on capital accumulation, labour supply, labour income, and output. These results are consistent with previous literature such as Kitao (2011). Increasing consumption tax rate also generates higher consumption and welfare gains when the consumption tax rate is lower than 55 percent. At the same time, we observe less wealth inequality and earnings inequality while higher consumption inequality and disposable income inequality. The earnings inequality and disposable income inequality results under the condition that the consumption tax rate is lower than 55 percent are consistent with that of Nakajima and Takahashi (2020). When the consumption tax rate is higher than 55 percent, there is a negative effect on consumption and social welfare. The earnings inequality increases, and the disposable income inequality decreases. Moreover, we conduct two sets of progressive consumption tax experiments. In both sets of experiments, a consumption threshold provides a tax free range of consumption. This gives the low income individuals more incentive to increase their consumption and decrease their savings. Moreover, higher consumption tax rates make the high income individuals consume less and save more. These two effects, in turn, generate lower consumption inequality and higher wealth inequality. In addition, a higher consumption tax progressivity generates an increase in social welfare and a decrease in the consumption inequality. Yet, it increases the wealth inequality. Without setting a higher tax rate for a higher level of consumption, setting tax exemption threshold generates substantial welfare losses. The presence of endogenous human capital accumulation does not change the direction of the results. In a nutshell, incorporating a proper progressive consumption tax system generates welfare gains and reduces consumption inequalities without hurting the wealth distribution much.

Chapter 3

Optimal Taxation, Differential Mortality, and Endogenous Human Capital Accumulation in China

3.1 Introduction

China has entered a fast growth phase since the economic reform in the 1970s. The most recent data shows that China has produced a GDP of 14.72 trillion in current U.S. dollars with the growth rate of 2.3% in 2020 according to the World Bank, which is almost 159 times of the GDP in 1990 ($92.603 billion) (see WB (2021a) and WB (2021b)). As reported in the 2021 China Statistical Yearbook (NBSC (2021b)), the per capita annual average earnings also raised from 5,348 yuan in 1995 to 97,379 yuan in 2020. Such rapid growth of the Chinese economy is catching lots of attention from economists. There is a number of quantitative studies try to understand Chinese economy such as Li and Mérette (2005), Li et al. (2015), İmrohoroğlu and Zhao (2018a), İmrohoroğlu and Zhao (2018b), and İmrohoroğlu and Zhao (2020). They focus on China's economic transition, social security reform, long-term care, family insurance, and pension reforms in China, respectively. This paper is interested in finding the optimal taxation for the Chinese economy.

In 2020, the tax revenue in China equalled approximately 16.4% of the total GDP, which is around 2.42 trillion in current U.S. dollars according to the 2021 China Statistical Yearbook (NBSC (2021b)). Since taxation has an important aggregate in the welfare implication, it would be worthwhile to analyze the optimal tax combination for the Chinese economy. In this paper, we try to find the optimal taxation bundle of the capital income tax rate, labour income tax rate, and consumption tax rate for China.

There is a large number of literature on taxation. For instance, Conesa et al. (2009), Chen et al. (2011), Gervais (2012), Kindermann and Krueger (2014), and Peterman (2016) study the optimal taxation from different aspects using large-scale overlapping generation (OLG) models. Our model follows this tradition. However, these quantitative literature focus on the U.S. economy while we are interested in the Chinese economy. In this paper, we do optimal taxation analysis for the Chinese economy follow these quantitative models.

Peterman (2016) shows that incorporating the endogenous human capital accumulation has important implications in finding optimal taxation: there is always an inter-temporal link between the current labour and the future human capital, which encourages the government to use age-dependent taxes. Incorporating the human capital or not hence affects the optimal tax policies. Zhao (2017) states that China has the largest higher education system in the world. The 2021 China Statistical Yearbook shows that the population with a graduate degree has increased from 1.4% in 1990 to 16.4% in 2020.[1] It is clear that the Chinese government pay lots of attention to the individuals' education, and the population receiving education is growing fast. Hence, it is important to incorporate human capital accumulation into our model. More specifically, we incorporate 'learning-by-doing' as a form of endogenous human capital accumulation into our model settings following Chen et al. (2011) and Peterman (2016).

On top of these, previous literature shows that there are different mortality rates among different income groups. It might also be important to incorporate differential mortality when analyzing the optimal taxation in China. However, current literature on differential mortality only focus on the U.S. economy such as Garrett (1995), Bommier et al. (2011), and Bishnu et al. (2019). These literature also do not focusing on optimal taxation. For instance, Bishnu et al. (2019) examine the pay-as-you-go social security system with the presence of differential mortality. They find that with the presence of differential mortality, the high-income group may benefit the most and increase the wealth inequality in a progressive social security system. It suggests that incorporating the differential mortality reverses the known results of social security literature. Differential mortality may have important implications from the taxation perspective, as well as in the Chinese economy. Therefore, we incorporate differential mortality into our model settings. In doing so, we

[1] The 2021 China Statistical Yearbook also shows that there is only 3.6% of the population above six years old had not received any education in 2020. At the same time, 16.4% of the population received education higher than high school, which was only 1.4% in 1990.

expect to generate a more comprehensive quantitative model for Chinese optimal taxation analysis.

In this paper, we try to find an optimal taxation combination for China under four different model settings: standard life-cycle model without human capital accumulation (NHC), NHC model with differential mortality (NHC+DM), the life-cycle model with human capital accumulation (HC), HC model with differential mortality (HC+DM). We calibrate our model economy to the Chinese economy. The benchmark models are able to match the target moments successfully.[2] First, we generate the benchmark economy with the taxation bundle as follows: the capital income tax rate and consumption tax rate are equal to 16.5%, the labour income tax system consists of a marginal tax rate of 17.8% and a fixed deduction of 97,215 yuan.[3] After this, We calculate the optimal tax bundles under each model setting. The optimal capital income tax rate is calculated as 8.1%, 7.9%, 2.6%, and 15.4% under NHC, NHC+DM, HC, and HC+DM models, respectively. The optimal consumption tax rate is calculated as 16.6%, 16.6%, 17.4%, and 13.6% in NHC, NHC+DM, HC, and HC+DM models, respectively. The optimal labour income taxes is a 41.6% marginal tax rate with 98,010 yuan of deduction, a 21.0% marginal rate with 97,253 yuan deduction, a 3.1% marginal rate with 96,225 yuan deduction, and an 18.5% marginal rate with 97,535 yuan deduction, respectively.

In the NHC model, when moving from the baseline model to the optimal model, the aggregate output increases by 2.9%, aggregate capital increases by 8.5%, aggregate labour supply decreases by 2.7%, wage rate increases by 3.5%, and interest rate decreases by 11.5%. The optimal model generates social welfare gains which is given by 3.18% using the CEV measure. In the NHC+DM model, when moving from the baseline model to the optimal model, the aggregate output increases by 2.7%, aggregate capital increases by 8.1%, aggregate labour supply decreases by 2.9%, wage rate increases by 3.4%, and interest rate decreases by 11.4%. The optimal model generates 3.07% of CEV. We find that incorporating differential mortality into the NHC model, the results in the optimal model do not change much. In the HC model, when moving from the baseline model to the optimal model, the aggregate output increases 3.7%, aggregate capital increases by 18%,

[2]We target capital-income ratio, average Frisch elasticity, average working hours, and Gini coefficients (wealth and labour income).

[3]The fixed deduction of 97,215 yuan is an average of the deductions in the four baselines: 97,239 yuan in NHC model, 97,238 yuan in NHC+DM model, 97,145 yuan in HC model, and 97,237 yuan in HC+DM model.

aggregate labour supply decreases by 8.8%, wage rate increases by 3.8%, and interest rate decreases by 24.1%. The optimal model generates 17.1% of social welfare gains (CEV). In the HC+DM model, when moving from the baseline model to the optimal model, the aggregate output increases 2.1%, aggregate capital increases by 4.7%, aggregate labour supply decreases by 0.3%, wage rate increases by 2.2%, and interest rate decreases by 5.1%. The optimal model generates a CEV equal to 3.33%. When incorporating the differential mortality, the results in the optimal model change more significantly in the HC case than the NHC case.

Finally, we show that differential mortality has similar implications on both low skilled and high skilled individuals, especially under the exogenous human capital accumulation environment. In all, we find that the optimal tax bundles under each model are different for China. An optimal bundle always includes a decrease in capital tax rate and an increase in fixed deductions. Incorporating the differential mortality generates different results in NHC and HC models. Since human capital is an important feature of the Chinese economy and differential mortality exists among most countries, it would be better to incorporate both human capital accumulation and differential mortality as part of a more comprehensive Chinese model.

This paper is organized as follows. Section 3.2 explains the model environment. Section 3.3 describes the calibration process. Section 3.4 states the experiment results. Section 3.5 concludes.

3.2 The model

We use a large-scale overlapping generations model with uninsurable labour productivity risks following Peterman (2016).

3.2.1 Individuals

Demographics. Time is assumed to be discrete with one year intervals. Individuals start to work at age 20, live a finite J years, and retire at age $j_r < J$. They have probability $\psi_j < 1$ at age j to live to age $j+1$ where $j \in \mathbb{J} = \{20, 21, ..., J+20\}$. Once they die, their bequests beq_t will be redistributed automatically and equally among all living individuals.

Preferences. In each period, each individual i is endowed with no assets but one unit of time, which is divided into productive labour $(h_{i,j})$ and leisure $(1-h_{i,j})$ at age j. The wage an individual earns in the labour market is given by $w\omega_{i,j}h_{i,j}$ where $\omega_{i,j}$ is the idiosyncratic labour productivity. Following Kaplan (2012), this idiosyncratic productivity $\omega_{i,j}$ can be written as follows:

$$\begin{aligned} \log \omega^{e}_{i,j} &= \varepsilon^{e}_{j} + \zeta_i + \upsilon_t + \eta_\iota, \\ \log \omega^{l}_{i,j} &= \varepsilon^{l}_{i,j} + \zeta_i + \upsilon_t + \eta_\iota, \end{aligned} \tag{3.1}$$

where $\omega^{e}_{i,j}$ and $\omega^{l}_{i,j}$ represent the idiosyncratic labour productivity in the non human capital accumulation (NHC) model and the human capital accumulation (HC) model, respectively. ζ_i represents a fixed effect known as 'ability'. ε^{e}_{j} and $\varepsilon^{l}_{i,j}$ represent the age-specific human capital. ε^{e}_{j} is exogenously determined in the NHC model. On the other hand, $\varepsilon^{l}_{i,j}$ is determined by its lagged calibration parameter, human capital, and leisure in the HC model. To be more specific, we set the age-specific human capital in the HC model following Hansen and İmrohoroğlu (2009) as follows:

$$\varepsilon^{l}_{i,j} = \Theta_{j-1}(\varepsilon^{l}_{i,j-1})^{\Phi_1}(h_{i,j-1})^{\Phi_2}, \tag{3.2}$$

where Θ_j, Φ_1, and Φ_2 are the parameters that govern the sequence of $\varepsilon^{l}_{i,j}$ so that $\varepsilon^{l}_{i,j}$ in the HC model matches with ε^{e}_{j} in the NHC model. As individuals work more, they accumulate more human capital. The human capital is always positive since the individuals always provide a positive amount of labour in the optimization problem. The persistent shock υ_t follows an AR(1) process:

$$\upsilon_t = \rho\upsilon_{t-1} + \varepsilon_t \tag{3.3}$$

with $\varepsilon_t \sim NID(0, \sigma^2_\upsilon)$ and $\upsilon_0 = 0$. The transition shock to productivity $\eta_t \sim NID(0, \sigma^2_\eta)$. Moreover, individuals are divided into two groups according to their skill levels. Normally the skill levels also represents their educational level. Here, we use $\iota \in \{H, L\}$ to stand for high or low skilled individuals, respectively. All individuals maximize their own lifetime utility by choosing the amount of consumption $(c_{i,j})$, labour $(h_{i,j})$, and savings $(a_{i,j})$:

$$u(c_{i,j}, h_{i,j}) + \sum_{s=1}^{J-j+1} \beta^s \prod_{q=1}^{s} (\psi_q) u(c_{i,s+1}, h_{i,s+1}), \tag{3.4}$$

where β is the time discount factor and ψ_q is the survival probability of living to age $j+1$ conditional on being alive at age j.

3.2.2 Technology

Aggregate technology follows a constant return to scale representation modeled by Cobb-Douglas production function:

$$F(K_t, N_t) = A_t K_t^{\alpha} N_t^{1-\alpha}, \tag{3.5}$$

where α is the capital share of the output; K_t is the aggregate capital shock; and N_t is the aggregate labour. Firms are maximizing their profit in every period:

$$\Pi_t(K_t, N_t) = Y_t - w_t N_t - (r_t + \delta)K_t.$$

The first order condition gives the optimal choice of the firm setting the wage rate to the value of marginal productivity of labour and rental rate to the value of marginal productivity of capital with the following equations:

$$\begin{aligned} w_t &= A_t(1-\alpha)k_t^{\alpha}, \\ r_t &= A_t \alpha k_t^{\alpha-1} - \delta, \end{aligned} \tag{3.6}$$

where k_t is the capital-labour ratio at time t, and $\delta < 1$ is the depreciation rate of physical capital. The technology parameter A_t is normalized to 1. The constraint of the aggregate resources is given as follows:

$$C_t + K_{t+1} - (1-\delta)K_t + G_t \leq K_t^{\alpha} N_t^{1-\alpha}, \tag{3.7}$$

where C_t is the aggregate consumption and G_t is the aggregate government expenditure.

3.2.3 Government Policy

The government collects taxes from labour income, capital income, and consumption in order to finance its expenditure G_t. Since two-thirds of pretax labour income are accounted for social security contribution by employers, the individual's taxable labour income is given by

$$y_{i,j}^l \equiv w_t \omega_{i,j} h_{i,j} - \frac{1}{3}\tau_{ss} \min\{w_t \omega_{i,j} h_{i,j}, \bar{y}\},$$

where $\bar{y}$ is the maximum amount that the individuals' labour income is taxed and τ_{ss} is the payroll tax rate.[4] The capital income is $y^k \equiv r_t(a + beq_t)$. Hence, the amount of total taxes is determined by four components: a non-linear tax schedule $T(\cdot)$ applying to the labour income $y_{i,j}^l$, a flat capital income tax rate τ_k applying to the capital income $y_{i,j}^k$, a flat consumption tax rate τ_c applying to the consumption $c_{i,j}$. The equation of the amount of total taxes at age j is given as follows:

$$T_j = T(y_{i,j}^l) + \tau_k(y_{i,j}^k) + \tau_c(c_{i,j}). \tag{3.8}$$

In addition, the government runs a pay-as-you-go (PAYG) social security system. Within this system, the government collects the payroll taxes and redistributes the amount of SS_t to the retired population. The payroll tax that each individual pays is given by $\tau_{ss} \min\{w\omega h, \bar{y}\}$.

3.2.4 Equilibrium Definition

In this section, we define the competitive equilibrium of this model. The state variables are: individual assets a, idiosyncratic productivity ω, and age j. These are jointly represented as $\Omega_t = (j, a_t, \omega_t)$ for the aggregate state of the economy at time t.

Definition 2 *Given a sequence of skill accumulation parameters* $\{\Theta_j\}_{j=20}^{j_r-1}$,[5] *payroll tax rate* $\{\tau_{ss}\}_{t=1}^{\infty}$, *capital income tax rate* $\{\tau_k\}_{t=1}^{\infty}$, *consumption tax rate* $\{\tau_c\}_{t=1}^{\infty}$, *government expenditure* $\{G_t\}_{t=1}^{\infty}$, *social security benefits* $\{SS_t\}_{t=1}^{\infty}$, *and a set of demographic parameters* $\{n, \psi_j\}$, *a tax function* $T : \mathbb{R}_+ \to \mathbb{R}_+$, *a maximum amount of taxable income for social security* $\bar{y}$, *a production plan for the firm* (N, K), *an age-specific human capital accumulation function* $S : \mathbb{R}_+ \times \mathbb{R}_+ \times \mathbb{R}_+ \to \mathbb{R}_+$, *and a utility function* $U : \mathbb{R}_+ \times \mathbb{R}_+ \to \mathbb{R}_+$, *a stationary competitive equilibrium consists of individuals' decision rules* $\{c, h\}$ *for each*

[4] 1/3 of the pre-tax labour income that is accounted for social security contribution, which is not taxed under the current Chinese tax code.

[5] The Θ sequence only applies to the HC and HC+DM models.

state κ, factor prices $\{w, r\}$, accidental bequests beq, and the distribution of individuals $\{\mu(\kappa)\}$ such that the following holds:

1. *The individual maximizes Equation (3.4) given prices $\{w, r\}$, polict $\{T\}$, accidental bequests $\{beq\}$, benefits $\{SS\}$, and idiosyncratic productivity $\{\omega\}$ subject to*

$$\begin{aligned} c + a' =& w\omega h - \frac{1}{3}\tau_{ss} w\omega h + (1+r)(a + beq) \\ & - T[w\omega h - \frac{1}{3}\tau_{ss}\min\{w\omega h, \bar{y}\})] - \tau_k[r(a+beq)] - \tau_c c, \end{aligned} \tag{3.9}$$

for $j \leq j_r$, and

$$c + a' = SS + (1+r)(a+beq) - \tau_k[r(a+beq)] - \tau_c c, \tag{3.10}$$

for $j > j_r$. And at the same time,

$$c \geq 0, 0 \leq h \leq 1, a \geq 0, a_1 = 0.$$

2. *The firm maximizes its profit according to Equation 3.4 where prices w and r satisfy*

$$r = \alpha(\frac{K}{N})^{\alpha-1} - \delta$$

and

$$w = (1-\alpha)(\frac{K}{N})^{\alpha}.$$

3. *The social security policies satisfy*

$$\tau_{ss} = \frac{\sum_{j>j_r} SS\mu(\kappa)}{\sum_{j\leq j_r}\min\{w\omega h, \bar{y}\}\mu(\kappa)}.$$

4. *Accidental bequests are given by*

$$beq = \sum(1-\psi)a'\mu(\kappa).$$

5. *Government balances its budget*

$$G = \sum_{j \leq j_r} T[w\omega h - \frac{1}{3}\tau_{ss}\min\{w\omega h, \bar{y}\})]\mu(\kappa) + \tau_k \sum[r(a + beq)]\mu(\kappa) + \tau_c \sum c\mu(\kappa). \tag{3.11}$$

6. *The market clears*

$$K = \sum a\mu(\kappa)$$
$$N = \sum \omega h\mu(\kappa),$$

and

$$\sum c\mu(\kappa) + \sum a'\mu(\kappa) + G = K^{\alpha}N^{1-\alpha} + (1-\alpha)K.$$

7. *The distribution of $\mu(\kappa)$ is stationary. The law of motion for the distribution of individuals over state space satisfies $\mu(\kappa) = Q_{\mu}\mu(\kappa)$, where Q_{μ} is a one-period recursive operator on the distribution.*

3.3 Calibration

We calibrate the model economy to the Chinese economy. Some parameters are taken from external sources such as previous literature and data. Some other parameters are calibrated to match the baseline steady state equilibrium with the empirical data. Table 3.1 shows the external parameters. Table 3.2 shows the calibrated parameters.

3.3.1 Demographics

We assume that agents start working at 20 years old, retire at 60, and may survive until age 100. The survive rate ψ_j is calculated based on the death rate from Census NBSC (2010) and population growth rate is 0.5% follows from China Statistical Yearbook NBSC (2021a).

Table 3.1: External parameters.

Parameter	Value	Target
Damographics		
Retire age: j_r	60	By assumption.
Max age: J	100	By assumption.
Sur. prob: ψ_j	$\{\psi_j\}$	Census 2010
Pop. growth: n	0.5%	China Statistical Yearbook 2020
Preferences		
Risk aversion: σ_1	3	Imrohoroglu & Zhao (2018a)
Firm parameters		
Capital share: α	0.5	Imrohoroglu & Zhao (2018a)
Depreciation rate: δ	10%	Imrohoroglu & Zhao (2018a)
Technology: A	1	Normalization
Productivity parameters		
Persistence shock: σ_υ^2	0.06	Imrohoroglu & Zhao (2018a)
Persistence: ρ	0.86	Imrohoroglu & Zhao (2018a)
Permanent shock: σ_ζ^2	0.291	He et al. (2019)
Transitory shock: σ_ε^2	0.036	He et al. (2019)
Government parameters		
Payroll tax: τ_{ss}	0.50	State Taxation Administration
Consumption tax: τ_c	0.165	State Taxation Administration
λ_0	0.178	Li & Ma (2017)
λ_1	2.617	Li & Ma (2017)
λ_2	0.002	Li & Ma (2017)
Human capital parameters		
Φ_1	0.296	Calculated based on Whalley and Zhao (2013)
Φ_2	0.123	Calculated based on Whalley and Zhao (2013)

Table 3.2: Calibration parameters.

Parameter	NHC	NHC+DM	HC	HC+DM	Target
Calibration parameter					
Discount factor: β	0.960	0.959	0.964	0.963	$\frac{K}{Y} = 2.7$
Frisch elasticity: σ_2	3.15	3.15	3.8	3.8	Frisch $= \frac{1}{2}$
Value of leisure: χ	1.03	1.04	0.92	0.93	Avg. $h_j = 0.388$
Government parameters					
G	14.2	14.2	14.2	14.2	14% of Y

Differential Mortality

When incorporating the differential mortality, we set the unconditional survival probabilities for {H, L} households separately. The unconditional survival probabilities are calculated based on the death rate provided in Census 2010 and an estimation of relative mortality hazard given different income groups provided by Luo and Xie (2020). The unconditional survival probabilities for both skill levels are shown in Figure 3.1.

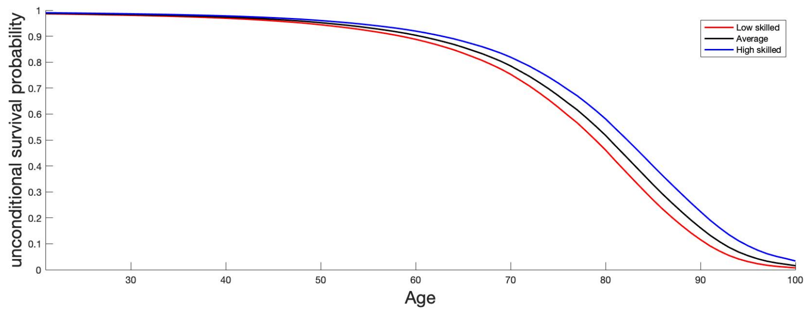

Figure 3.1: Unconditional survival probabilities for different groups.

3.3.2 Preferences and Endowments

The instantaneous utility function we use is:

$$u(c_t, 1-h_t) = \frac{c_t^{1-\sigma_1}}{1-\sigma_1} + \chi\frac{(1-h_t)^{1-\sigma_2}}{1-\sigma_2},$$

where χ represents the working disutility, σ_1 is the risk-aversion coefficient, and σ_2 is inverse of Frisch elasticity of labour supply. We calibrate β, the discount factor, to meet the target of capital-labour ratio to be 2.7 according to Roberts and Russell (2019). The risk aversion is set as $\sigma_1 = 3$ following from İmrohoroğlu and Zhao (2018a). We set $\sigma_2 = 3.15$ in the NHC and NHC+DM models and $\sigma_2 = 3.8$ in the HC and HC+DM models in order to obtain an average Frisch elasticity of labour supply as 0.5 following Peterman (2016) in all model settings.[6]

[6]

$$\text{Frisch} = \begin{cases} \frac{U_h U_{cc}}{h[U_{ch}^2 - U_{cc}U_{hh}]} & \text{in NHC and NHC+DM models,} \\ \frac{U_h U_{cc}}{h[U_{ch}^2 - U_{cc}U_{hh} + \frac{h'w'}{rws}(s'_h(U_{ch}^2 - U_{cc}U_{hh}) - U_{cc}U_h s'_{hh})]} & \text{in HC and HC+DM models.} \end{cases}$$

Notice that the Frisch elasticity is constant in the NHC and NHC+DM models. On the contrary, it is increasing in the HC and HC+DM models. Thus, when we do calibration for the HC and HC+DM models, we use the average Frisch elasticity as the target.

3.3.3 Idiosyncratic Labour Productivity

As we assumed, the agents are endowed with one unit of productive time in each period with labour ($h_{i,j}$) and leisure ($1 - h_{i,j}$). For each labour time, we have $\omega_{i,j}$ to be the idiosyncratic labour productivity. To be specific, $\omega_{i,j}$ depends on the age j, skill level ι, and an idiosyncratic shock η. For this idiosyncratic shock η, we assume that it takes 7 values for each skill-level of agents. The permanent and transitory idiosyncratic labour productivity shocks are calibrated based on the He et al. (2019). They are normally distributed with zero mean and variance to be $\sigma_\zeta = 0.291$ and $\sigma_\upsilon = 0.06$ respectively. According to İmrohoroğlu and Zhao (2018a), the persistent shock is normally distributed with zero mean and variance $\sigma_\varepsilon = 0.081$. The persistence $\rho = 0.86$ also follows İmrohoroğlu and Zhao (2018a).

3.3.4 Age-specified Human Capital

The values of age-specified human capital, ε_j, are taken from He et al. (2019). Parameters $\phi_1 = 0.296$ and $\phi_2 = 0.123$ are set based on the estimation given by Whalley and Zhao (2013).[7]

3.3.5 Government Policy

The concrete tax function we use to tax the individual's labour and capital income follows from Gouveia and Strauss (1994) progressive tax function:

$$T_t(y_t) = \lambda_0(y_t - ((y_t)^{-\lambda_1} + \lambda_2)^{-\frac{1}{\lambda_1}}). \tag{3.12}$$

The parameter λ_0 principally controls the average tax rate, and λ_1 governs the curvature of the tax function, i.e. the progressivity of the tax policy. Following estimation by Li and Ma (2017), λ_0 is set to be 0.178, λ_1 is 2.617, and λ_2 is 0.002 for 2009 sample. In our model, we use λ_2 to balance the budget. The government runs a pay-as-you-go social security system that is financed by a payroll rate τ_{ss}.

[7] Whalley and Zhao (2013) shows that the contribution of labour and human capital to the production growth are 3.97% and 9.70%, respectively.

3.4 Results

3.4.1 Baseline results

In this section, we show the benchmark results under each model settings (NHC, NHC+DM, HC, and HC+DM models). These four benchmarks are calibrated separately to meet the target moments, as stated in Section 3.3 (see Table 3.2). Table 3.3 demonstrates the aggregate economic variables under all models. The benchmark results are relatively close to each other. These four models are used as baseline models for later experiments. In addition, all models generate the income Gini coefficient and the wealth Gini coefficient close to what was observed in the Chinese data (see Table 3.4). We also observe that the HC and HC+DM models generate closer labour income Ginis while the NHC and NHC+DM models generate closer wealth Ginis to the data.

Table 3.3: Aggregate economic variables

	NHC	NHC+DM	HC	HC+DM
Y	1.00	1.01	1.06	1.04
K	2.72	2.61	2.64	2.75
N	0.39	0.39	0.42	0.39
Avg. h	0.40	0.40	0.42	0.39
w	0.73	0.72	0.76	0.75
r	0.096	0.094	0.100	0.088
beq	0.026	0.026	0.029	0.026

Table 3.4: Gini coefficients

	Data	NHC	NHC+DM	HC	HC+DM
labour income	0.38	0.33	0.33	0.37	0.36
wealth	0.62	0.63	0.62	0.67	0.65

Notes: Data is taken from World Bank and China Statistical Yearbook 2020

Figure 3.2 shows the results of the average unit of time individuals spend on working, the average consumption, the median savings, and the average earnings for each benchmark models. The blue line, red line, dashed blue line and dashed red line represent the benchmark results in the NHC model, NHC+DM model, HC model, and the HC+DM model, respectively.

The models generate downward-sloping labour supplies. The reason is that young individuals need to consume and accumulate precautionary savings since they enter the

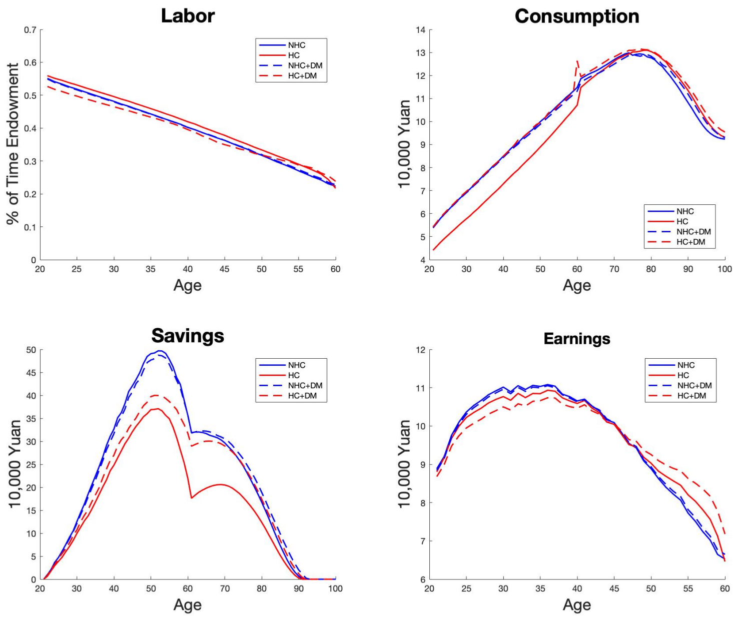

Figure 3.2: NHC, HC, NHC+DM and HC+DM Baseline life-cycle profiles

model with no assets. As the workers accumulate more experience and wealth, they decrease their working hours overtime. All four models generate similar benchmark labour supplies. The benchmark labour supply in the HC+DM model is relatively lower than the others.

The consumption plots have hump shapes in all the models. Individuals consume as much as they can before retirement. Then, at the age of 60, there is a small increase as the individuals retire and start to receive social security transfers. The consumption peaks at around age 75. After the age of 75, consumption decreases as savings decrease.

The savings show similar trends between all the models. All these plots have hump shapes and peak at around the age of 52. Intuitively, in the model, the savings increase as the individuals accumulate more assets while working and decreases after the age of 52 as earnings decrease. There is a further increase in savings after the individuals' retirement due to the social security transfers. The savings plots then peak around the age of 70. After the age of 70, the savings decreases in all models. What is more, when incorporating the differential mortality, we generate a higher baseline saving profile than the HC model.

The labour income profiles show hump shapes in all four plots, which peak around the age of 38. In the model, all individuals are forced to work until the age of 60 unless they die before. There is little difference between the NHC+DM model and the NHC model.

However, incorporating the differential mortality in the HC model shifts the income from young to old employees. It suggests that employers would like to pay less to the less experienced (younger) employers while paying more to those who are more experienced (older).

3.4.2 Optimal Policies

In this section, we search the optimal pair of capital income tax rate τ_k, consumption tax rate τ_c, and the parameters that determines the progressive income tax function (λ_0, λ_1, and λ_2 in Equation 3.12) while keeping the government expenditure unchanged.[8] The procedure of determining the optimal taxation bundle is described as follows: first, we search for the optimal capital tax rate while keeping all other baseline parameters unchanged. Next, we use the optimal capital tax rate and keep the parameters of the progressive labour income tax system intact to search of the optimal consumption tax rate. Finally, we use the optimal capital income tax rate and the optimal consumption tax rate to find the optimal combination of the progressive labour income tax parameters. In order to conduct welfare analysis, we use the consumption equivalent variation (CEV) measure. It is defined as the uniform increase in consumption a household needs to be indifferent between being born into a reformed economy and being born in the baseline economy. The functional form of the CEV is given as follows

$$cev = \left(\frac{V_e}{V_b}\right)^{\frac{1}{1-\sigma_1}} - 1, \tag{3.13}$$

where V_e represents the value function of the counterfactual experiments and V_b represents the value function of the baseline model. The optimal policy results of capital income tax rates, consumption tax rates, and labour income tax system, which consists of marginal tax rates and fixed deductions, are shown in Table 3.5.[9] The results show that the capital income tax rate decreases in all models. The consumption tax rate decreases in the HC+DM model. The marginal labour income tax rate decreases in the HC model. The marginal labour income tax rates and fixed deductions are moving in the same direction. To be more specific, when the marginal labour income tax rate increases (decreases), the

[8] We report the parameter results in Table C.2 in appendix.

[9] The fixed deduction is calculated based on λ_1 and λ_2 in Equation 3.12. The baseline fixed deduction in Table 3.5 reports the average value of the fixed deduction under four baseline models.

fixed deduction increases (decreases). Among the four models, the HC model generates the lowest capital income tax rate and labour income tax rate. It also generates the highest consumption tax rate and fixed deductions.

Table 3.5: Optimal policies

Tax Parameters	Baseline	NHC	NHC+DM	HC	HC+DM
Capital income tax rate τ_k	16.5%	8.1%	7.9%	2.6%	15.4%
Consumption tax rate τ_c	16.5%	16.6%	16.6%	17.4%	13.6%
Labour income tax system					
Marginal tax rate λ_0	17.8%	41.6%	21.0%	3.1%	18.5%
Fixed deduction	¥97,215	¥98,010	¥97,253	¥96,225	¥97,535

Tables 3.6 and 3.7 summarize the aggregate variables and CEVs for the four optimal

Table 3.6: Aggregate economic variables in NHC model

	Baseline	Optimal	% change	DM Bas.	DM Opt.	% change
Aggregate						
Y	1.00	1.03	+2.9%	1.01	1.03	+2.7%
K	2.72	2.81	+8.5%	2.61	2.82	+8.1%
N	0.39	0.38	-2.7%	0.39	0.38	-2.9%
Avg. hours	0.40	0.39	-2.4%	0.40	0.39	-2.4%
w	0.73	0.75	+3.5%	0.72	0.75	+3.4%
r	0.096	0.084	-11.5%	0.094	0.083	-11.4%
beq	0.026	0.027	+4.6%	0.026	0.027	+3.0%
CEV		+3.18%			+3.07%	
Gini coefficient						
Wealth	0.63	0.64	+3.0%	0.62	0.63	+1.5%
Earnings	0.33	0.34	+1.8%	0.33	0.34	+2.5%
Consumption	0.18	0.18	+0.4%	0.19	0.19	-0.1%
Disposable Inc.	0.20	0.20	+2.6%	0.20	0.20	+0.0%

taxation experiments, respectively. More specifically, Tables 3.6 and 3.7 show the difference between the baseline and the optimal policy under the NHC and HC environment, respectively. When the human capital accumulation is exogenous, the percentage change from baseline to optimal is decreased with the presence of differential mortality. For instance, the percentage increase in the output (GDP) of the NHC model transfer from baseline to optimal policy is 2.9%. After incorporating with the differential mortality, the percentage increase in the output (GDP) reduces to 2.7%. The percentage increase in capital stock from baseline to optimal decreases from 8.5% to 8.1%, the percentage increase in wage decreases from 3.5% to 3.4%, the percentage increase in transfer decreases from 4.6% to 3.0%, and the social welfare gains (CEV) decreases from 3.18% to 3.07%. In addition, incorporating the differential mortality increases the percentage change in income inequality from baseline to optimal from 1.8% to 2.5% in the NHC model while decreasing the percentage changes in other inequalities. In both NHC to NHC+DM models, the baseline-optimal percentage changes have the same sign. This suggests that incorporating the differential mortality does not change the direction of optimal aggregate results. The social welfare gains (CEV) also decreases. We observe similar pattern in aggregate effects in the HC models (see Table 3.7). When incorporating differential

Table 3.7: Aggregate economic variables in HC model

	Baseline	Optimal	% change	DM Bas.	DM Opt.	% change
Aggregate						
Y	1.06	1.09	+3.7%	1.04	1.06	+2.1%
K	2.64	3.11	+18.0%	2.75	2.88	+4.7%
N	0.42	0.39	-8.8%	0.39	0.39	-0.3%
Avg. hours	0.42	0.39	-7.4%	0.39	0.39	-1.4%
w	0.76	0.79	+3.8%	0.75	0.77	+2.2%
r	0.100	0.076	-24.1%	0.088	0.084	-5.1%
beq	0.029	0.033	+12.2%	0.026	0.028	+5.4%
CEV		+17.10%			+3.33%	
Gini coefficient						
Wealth	0.67	0.67	+0.5%	0.65	0.67	+3.5%
Earnings	0.37	0.37	-0.5%	0.36	0.37	+3.0%
Consumption	0.23	0.22	-7.1%	0.21	0.21	+3.4%
Disposable Inc.	0.24	0.23	-2.3%	0.22	0.23	+5.5%

mortality, the percentage increase in output from baseline to optimal in HC decreases from 3.7% to 2.1%, the percentage increase in capital stock decreases from 18% to 4.7%, the percentage increase in wages decreases from 3.8% to 2.2%, the percentage increase in transfer decreases from 12.2% to 5.4%, and the social welfare gains (CEV) decreases from 17.1% to 3.33%. Different from the NHC model, the four inequalities (wealth, earnings, consumption, and disposable income Ginis) all increase.

In Figures 3.3 to 3.6, we show the baseline (blue line) and optimal (red line) comparison in labour supply, consumption, savings, labour income, total taxes paid, total taxable income, and disposable income in the NHC and NHC+DM models. When comparing the baseline and optimal results in the NHC model (see Figures 3.3 and 3.4), we observe that the optimal labour supply, optimal consumption, optimal savings, optimal labour income, optimal total taxes paid, optimal total taxable income, and optimal disposable income are all higher than the baseline profiles. The same pattern can be observed in the NHC+DM model as well (see Figures 3.5 and 3.6). When comparing the baseline-optimal distance in the NHC model with the baseline-optimal distance in the NHC+DM model, we observe that the distance between the baseline and optimal is relatively larger in the NHC model. Intuitively, incorporating the differential mortality makes the optimal tax policy in the NHC model closer to the baseline NHC model.

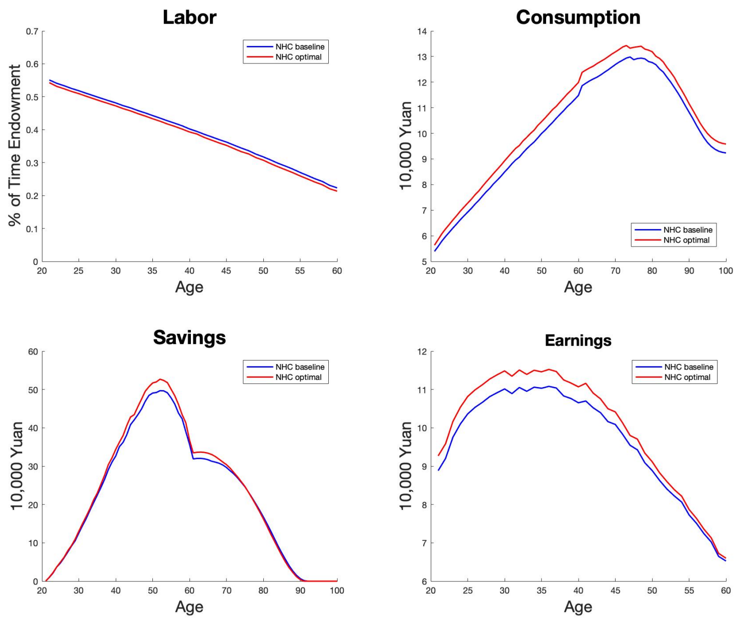

Figure 3.3: NHC baseline and optimal life-cycle profiles

Similarly, in Figures 3.7 to 3.10, we show the baseline (blue line) and optimal (red line) comparison in labour supply, consumption, savings, labour income, total taxes paid, total taxable income, and disposable income in the HC and HC+DM models, respectively. It shows that the optimal tax policy increases consumption, savings, earnings, and disposable income while decreasing the amount of total taxes paid. When incorporating the differential mortality, the optimal savings in the HC model decreases. With more disposable income in the optimal case, a larger increase in optimal consumption would lead to lower savings. Intuitively, with differential mortality, low skilled individuals may consume more and

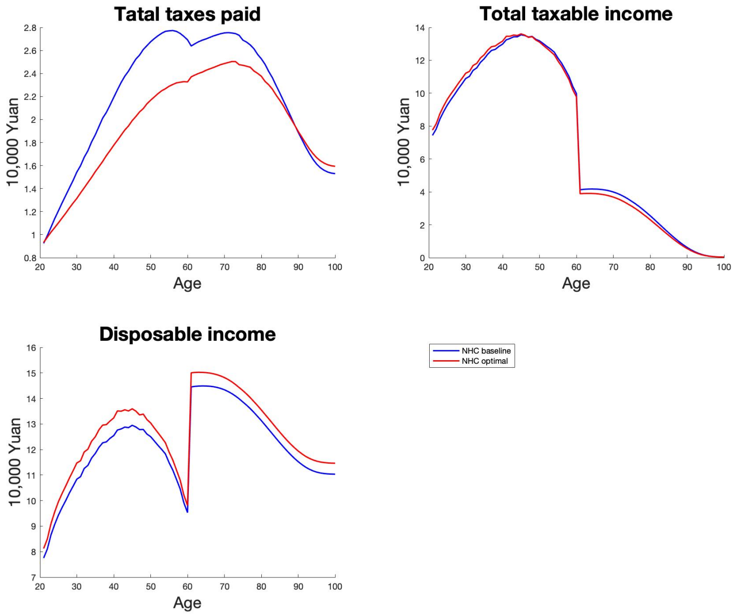

Figure 3.4: NHC baseline and optimal life-cycle profiles (cont.)

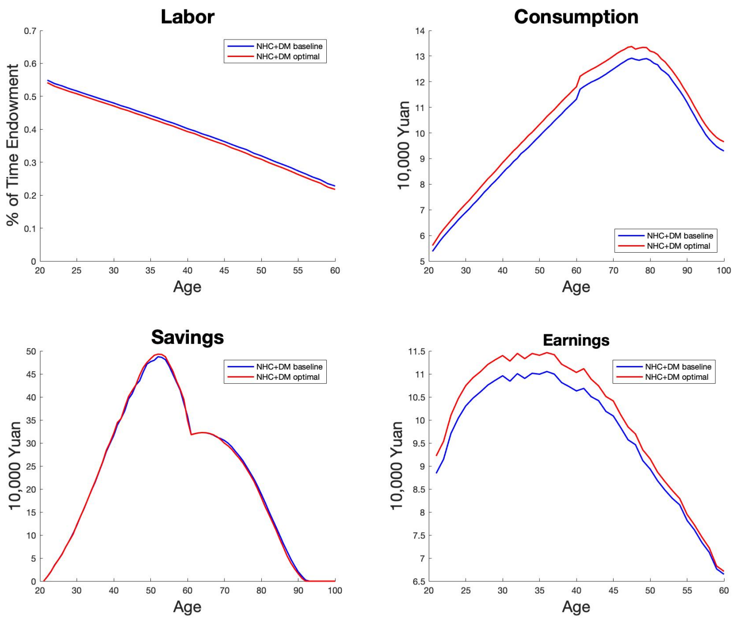

Figure 3.5: NHC+DM baseline and optimal life-cycle profiles

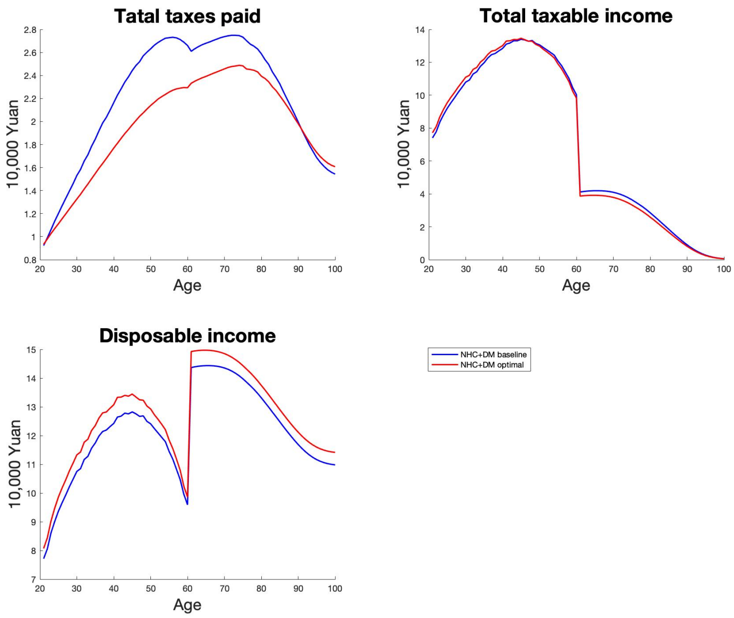

Figure 3.6: NHC+DM baseline and optimal life-cycle profiles (cont.)

save less since they expect lower survival probabilities. What is more, the differences (or distance) between the baseline and the optimal become smaller in labour supply and savings. On the contrary, the baseline-optimal distance becomes larger in consumption and average earnings when incorporating the differential mortality into the HC model. On the other hand, there is only a slight decrease in the labour supply, savings, and total taxable income. We also observe an increase in the consumption, earnings, and disposable income. What is more, there is a big decrease in the total taxes paid when implementing the optimal tax policy (see Figures 3.9 and 3.10). Again, incorporating the differential mortality makes the optimal tax policy in the HC model closer to the baseline HC model.

In all four models, implementing the optimal policy decreases the capital tax rate and interest rates at the same time. These two opposite effects determine the savings decisions jointly. First, a decrease in capital tax rate provides a higher incentive for individuals to save. Second, a decrease in the interest rate shifts the individuals' favour of saving to consuming. The overall result shows that optimal savings in the NHC and HC models increase, while the optimal savings in the models with differential moralities decrease. Due to the increase in labour income, individuals have more disposable income. As a result of shifting the favour of saving to consuming, the consumption in all four models increases.

We also show the comparison between baseline and optimal consumption, savings,

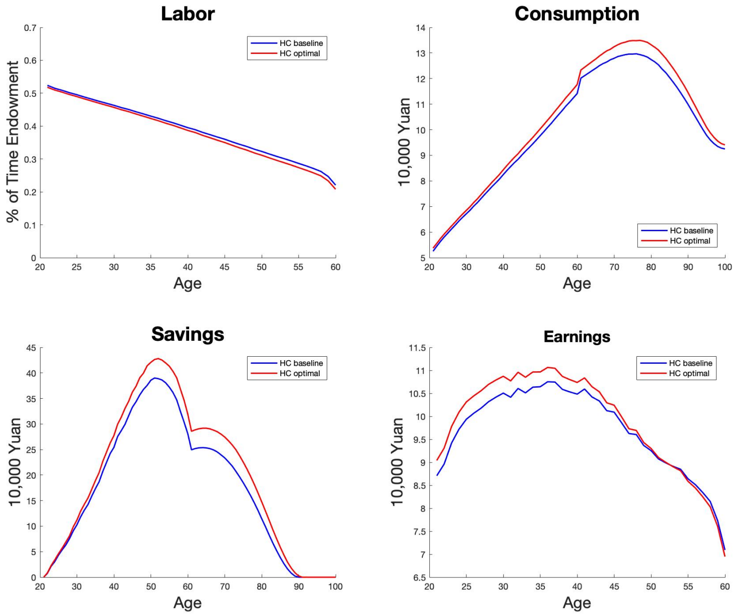

Figure 3.7: HC baseline and optimal life-cycle profiles

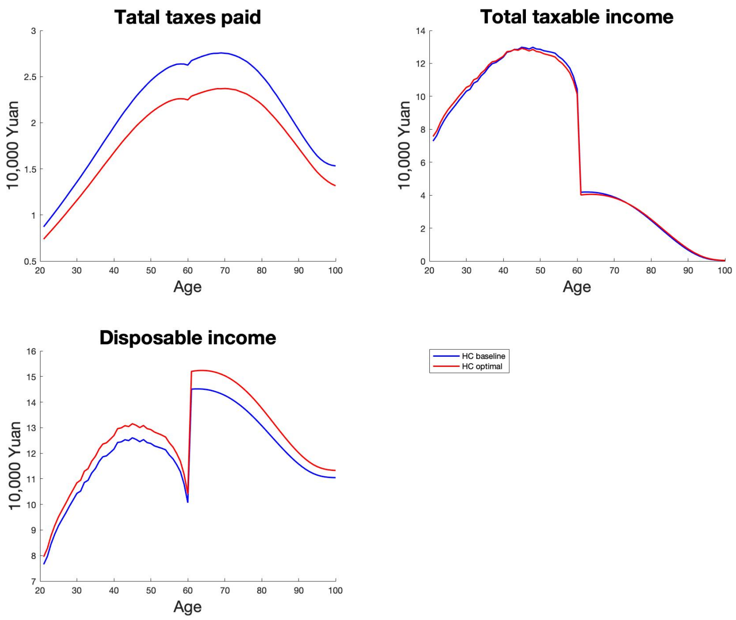

Figure 3.8: HC baseline and optimal life-cycle profiles (cont.)

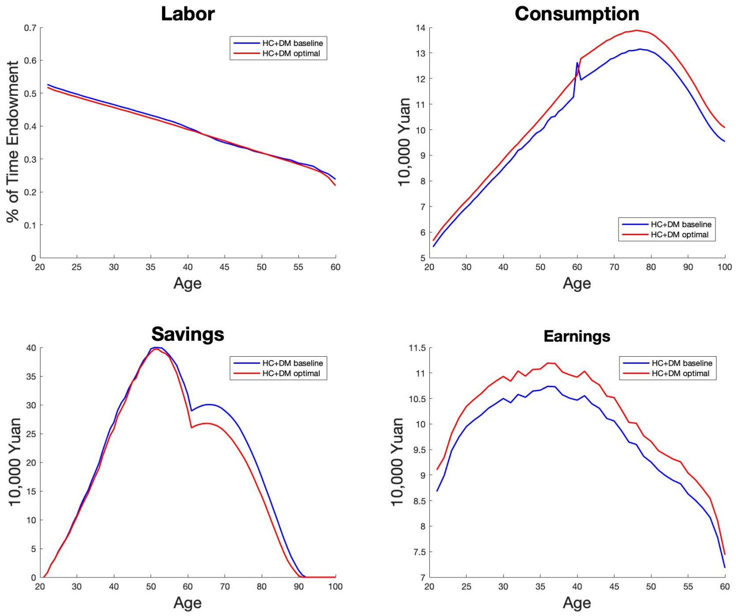

Figure 3.9: HC+DM baseline and optimal life-cycle profiles

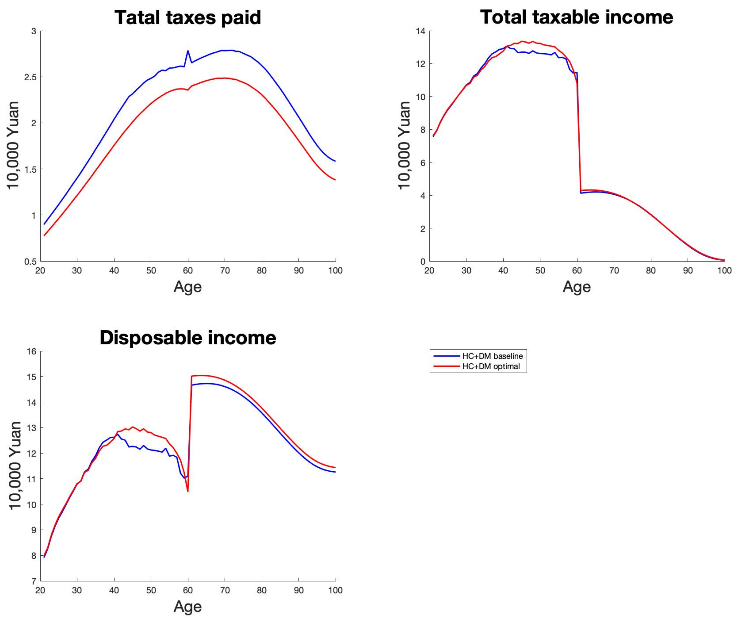

Figure 3.10: HC+DM baseline and optimal life-cycle profiles (cont.)

and labour supply in both low and high skilled groups among the four models.[10] The figures show the same pattern in all four models that incorporating differential shrinks the difference between the baseline and optimal in both skilled groups. For instance, for the labour supply in the HC model (see upper right of Figure C.14), the decrease of optimal labour supply from baseline for age 21 is approximately 0.05 of time endowment (equivalently 72 minutes) for both skilled groups. In the meanwhile, the decrease of labour supply from baseline to optimal is approximately 0.01 of time endowment (equivalently 14.4 minutes) (see upper right of Figure C.15).

3.5 Conclusion

In this paper, we calculate the optimal tax policy bundle for the Chinese economy. We show the implications of optimal taxation on aggregates, social welfare, and inequalities using an overlapping generation model. More specifically, we develop four models in this paper as follows: the standard life-cycle model with no endogenous human capital accumulation (NHC), the standard life-cycle model with differential mortality (NHC+DM), the life-cycle model with endogenous human capital accumulation (HC), and the life-cycle endogenous human capital model with differential mortality (HC+DM). We calibrate our baseline economy to the Chinese economy. Our baseline models capture the important features in the Chinese economy, such as capital-output ratio, average working hours, average Frisch elasticity, and inequalities.

In the baseline models, we have a capital income tax rate of 16.5%, a consumption tax rate of 16.5%, and a labour income tax system which consists of the marginal labour income tax rate of 17.8% with 97,215 yuan of fixed deduction. We find that the corresponding optimal tax bundle under each model are $[8.1\%, 16.6\%, (41.6\%, ¥98,010)]$ in the NHC model, $[7.9\%, 16.6\%, (21.0\%, ¥97,253)]$ in the NHC+DM model, $[2.6\%, 17.4\%, (3.1\%, ¥96,225)]$ in the HC model, and $[15.4\%, 13.6\%, (18.5\%, ¥97,535)]$ in the HC+DM model. Our results from generating the baseline results show that, in the HC model, incorporating the differential mortality accumulation shifts the labour income from young employees to older employees. This suggests that the employers favour the employees who are more experienced and more likely to survive to another period. In addition, when implementing

[10]For full figures, please see Figures C.12 to C.15 in the appendix.

the optimal tax policies, incorporating the differential mortality generates optimal policy results closer to the baselines despite individuals' skilled types in the exogenous human capital accumulation model. Similarly, the differential mortality generates less baseline-optimal labour supply, total taxable income, and disposable income under the endogenous human capital accumulation environment–however, the difference between baseline and optimal consumption and earnings increases. Intuitively, differential mortality with endogenous human capital accumulation affects the individual's decision on consumption since the low skilled individuals expect a shorter lifespan and may decide to enjoy their lives while they can (they increase the consumption and reduce savings). Incorporating the differential mortality decreases the welfare gains when implementing the optimal tax policies without changing the direction of aggregate results.

In a nutshell, we show that the optimal tax bundles differ across different model settings. The existence of differential mortality has a more significant effect under the endogenous human capital environment. We incorporate endogenous human capital accumulation since human capital accumulation is important for the Chinese economy. And differential mortality is important as incorporating different mortality rates across different income groups. From the Chinese economy's perspective, it would be good to incorporate both human capital accumulation and differential mortality.

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Appendix A

Appendix for Chapter 1

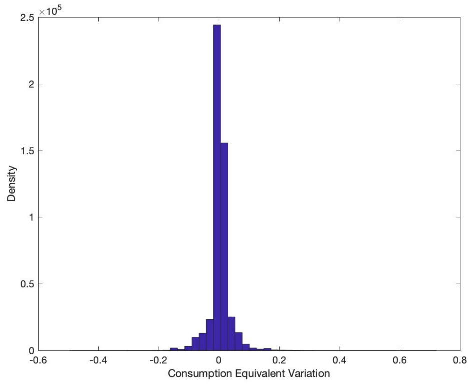

Figure A.1: Histogram of cev_i for E_1

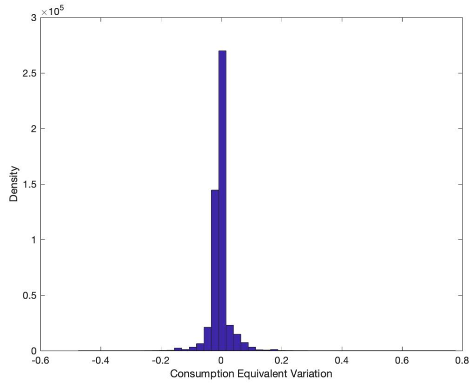

Figure A.2: Histogram of cev_i for E_2

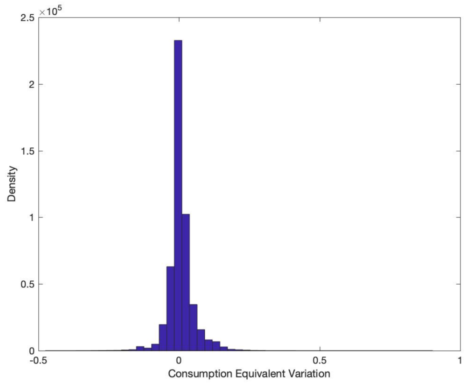

Figure A.3: Histogram of cev_i for E_3

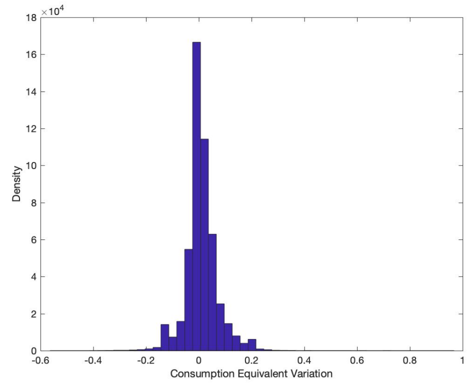

Figure A.4: Histogram of cev_i for E_4

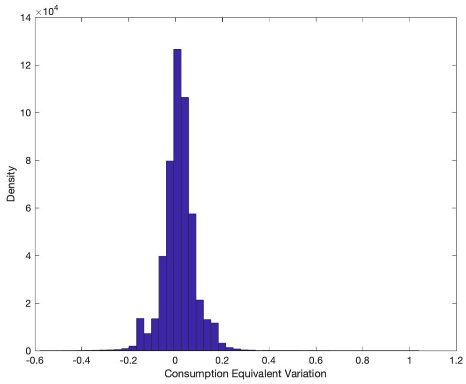

Figure A.5: Histogram of cev_i for E_5

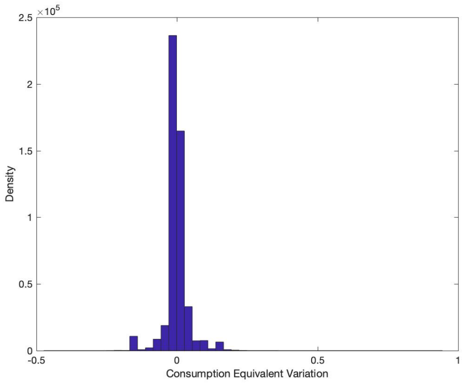

Figure A.6: Histogram of cev_i for E_6

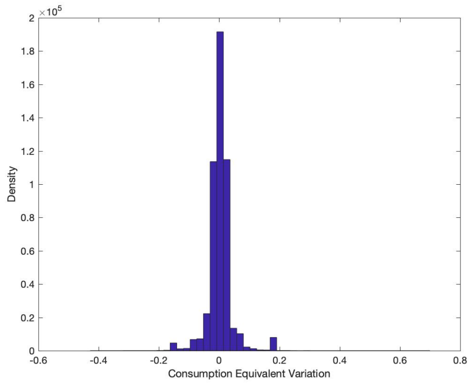

Figure A.7: Histogram of cev_i for E_7

Appendix B

Appendix for Chapter 2

B.1 Markov Chain for Labour Productivity

The Markov chain governing idiosyncratic labour productivity for both education groups is given as follows:

Table B.1: Markov Chain for labour productivity

i,j	1	2	3	4	5	6	7
1	0.91820496	0.07878367	0.00253492	0.00003625	0.00000019	0.00044000	0.00000000
2	0.01969592	0.9194724	0.05911494	0.00126765	0.00000906	0.00044000	0.00000000
3	0.00042249	0.03940996	0.91989510	0.03940996	0.00042249	0.00044000	0.00000000
4	0.00000906	0.00126765	0.05911494	0.91947242	0.01969592	0.00044000	0.00000000
5	0.00000019	0.00003625	0.00253492	0.07878367	0.91820496	0.00044000	0.00000000
6	0.00000000	0.00000000	0.00226600	0.00000000	0.00000000	0.97000000	0.02773400
7	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00074600	0.99925400
η_L	0.568	0.568	0.568	0.571	3.502	15.313	1254.012
η_H	1.004	1.004	1.004	1.010	6.187	8.720	1254.012

B.2 Tables

Table B.2: Progressive consumption tax reform

HCA	Baseline	0.03, 0.05	% change	0.03, 0.10	% change	0.03, 0.15	% change
Aggregate							
Y	1.17	1.16	-0.8%	1.16	-0.6%	1.16	-0.5%
K	3.14	3.05	-2.9%	3.10	-1.3%	3.13	-0.4%
N	0.67	0.67	+0.4%	0.67	-0.2%	0.67	-0.5%
Avg. hours	0.30	0.30	-0.2%	0.30	-0.9%	0.30	-1.1%
w	0.91	0.91	-0.7%	0.91	-0.7%	0.91	-0.4%
r	0.051	0.054	+5.7%	0.052	+2.1%	0.051	-0.2%
beq	0.037	0.036	-3.9%	0.036	-3.2%	0.037	-2.1%
CEV		-1.14%		0.57%		2.41%	
Gini							
Consumption	0.31	0.31	-0.9%	0.30	-2.8%	0.29	-5.2%
Wealth	0.69	0.68	-0.4%	0.68	-0.2%	0.68	-0.3%
Average tax rate							
Labour	0.1245	0.1251		0.1255		0.1258	
Capital	0.0861	0.0865		0.0863		0.0860	
Ratio	1.4450	1.4461		1.4543		1.4632	
Marginal tax rate							
Labour	0.1709	0.1715		0.1718		0.1721	
Capital	0.1346	0.1349		0.1347		0.1344	
Ratio	1.2697	1.2709		1.2756		1.2806	

Table B.3: Progressive consumption tax reform (cont.)

HCA	Baseline	0.04, 0.05	% change	0.04, 0.10	% change	0.04, 0.15	% change
Aggregate							
Y	1.17	1.16	-0.5%	1.17	-0.4%	1.16	-0.3%
K	3.14	3.10	-1.6%	3.14	-0.1%	3.17	+0.8%
N	0.67	0.67	+0.1%	0.67	-0.5%	0.67	-0.9%
Avg. hours	0.30	0.30	-0.3%	0.30	-1.0%	0.30	-1.2%
w	0.91	0.91	-0.4%	0.91	-0.4%	0.91	-0.3%
r	0.051	0.052	+2.9%	0.050	-0.7%	0.049	-2.9%
beq	0.037	0.037	-2.2%	0.037	-2.0%	0.037	-0.4%
CEV		-0.72%		1.04%		2.85%	
Gini							
Consumption	0.31	0.31	-0.3%	0.30	-2.4%	0.29	-4.5%
Wealth	0.69	0.68	-0.1%	0.69	+0.1%	0.69	+0.1%
Average tax rate							
Labour	0.1245	0.1249		0.1252		0.1255	
Capital	0.0861	0.0864		0.0861		0.0858	
Ratio	1.4450	1.4454		1.4542		1.4618	
Marginal tax rate							
Labour	0.1709	0.1713		0.1716		0.1718	
Capital	0.1346	0.1348		0.1345		0.1343	
Ratio	1.2697	1.2703		1.2752		1.2795	

Table B.4: Progressive consumption tax reform (cont.)

HCA	Baseline	0.05, 0.05	% change	0.05, 0.10	% change	0.05, 0.15	% change
Aggregate							
Y	1.17	1.17	-0.2%	1.17	-0.2%	1.17	-0.1%
K	3.14	3.13	-0.3%	3.17	+1.0%	3.21	+2.0%
N	0.67	0.67	-0.1%	0.67	-0.8%	0.66	-1.3%
Avg. hours	0.30	0.30	-0.5%	0.30	-1.0%	0.30	-1.5%
w	0.91	0.91	-0.3%	0.91	-0.2%	0.91	-0.1%
r	0.051	0.051	+0.4%	0.049	-2.9%	0.048	-5.4%
beq	0.037	0.037	-0.2%	0.038	+0.1%	0.038	+0.7%
CEV		-0.37%		1.64%		3.31%	
Gini							
Consumption	0.31	0.31	+0.3%	0.31	-2.0%	0.31	-4.2%
Wealth	0.69	0.68	-0.1%	0.69	+0.4%	0.69	+0.5%
Average tax rate							
Labour	0.1245	0.1246		0.1248		0.1252	
Capital	0.0861	0.0862		0.0859		0.0858	
Ratio	1.4450	1.4457		1.4525		1.4598	
Marginal tax rate							
Labour	0.1709	0.1710		0.1712		0.1716	
Capital	0.1346	0.1346		0.1344		0.1342	
Ratio	1.2697	1.2702		1.2740		1.2783	

Table B.5: Progressive consumption tax reform (cont.)

non HCA	Baseline	0.03, 0.05	% change	0.03, 0.10	% change	0.03, 0.15	% change
Aggregate							
Y	1.18	1.18	-0.7%	1.18	-0.3%	1.19	+0.02%
K	3.17	3.08	-2.7%	3.15	-0.3%	3.21	+1.5%
N	0.68	0.69	+0.4%	0.68	-0.3%	0.68	-0.8%
Avg. hours	0.33	0.33	-0.4%	0.33	-1.2%	0.33	-1.9%
w	0.93	0.92	-0.7%	0.92	-0.3%	0.93	+0.01%
r	0.052	0.054	+5.3%	0.052	+0.1%	0.050	-3.8%
beq	0.040	0.039	-2.9%	0.040	-1.5%	0.040	-0.2%
CEV		-0.76%		1.84%		4.19%	
Gini							
Consumption	0.34	0.33	-0.9%	0.33	-3.4%	0.32	-6.1%
Wealth	0.76	0.76	-0.04%	0.76	+0.2%	0.76	+0.1%
Average tax rate							
Labour	0.1259	0.1263		0.1265		0.1268	
Capital	0.0976	0.0983		0.0978		0.0973	
Ratio	1.2897	1.2856		1.2941		1.3036	
Marginal tax rate							
Labour	0.1723	0.1726		0.1728		0.1731	
Capital	0.1455	0.1461		0.1456		0.1451	
Ratio	1.1841	1.1819		1.1871		1.1927	

Table B.6: Progressive consumption tax reform (cont.)

non HCA	Baseline	0.04, 0.05	% change	0.04, 0.10	% change	0.04, 0.15	% change
Aggregate							
Y	1.18	1.18	-0.5%	1.19	-0.05%	1.19	+0.2%
K	3.17	3.12	-2.7%	3.19	-0.3%	3.25	+2.7%
N	0.68	0.68	+0.1%	0.68	-0.6%	0.68	-1.1%
Avg. hours	0.33	0.33	-0.6%	0.33	-1.4%	0.33	-2.2%
w	0.93	0.92	-0.5%	0.93	-0.05%	0.93	+0.2%
r	0.052	0.053	+2.8%	0.050	-2.4%	0.047	-6.2%
beq	0.040	0.040	-1.7%	0.040	-0.3%	0.041	+0.9%
CEV		-0.43%		2.31%		4.64%	
Gini							
Consumption	0.34	0.34	-0.3%	0.33	-2.9%	0.32	-5.5%
Wealth	0.76	0.76	-0.1%	0.76	+0.1%	0.76	+0.1%
Average tax rate							
Labour	0.1259	0.1262		0.1264		0.1267	
Capital	0.0976	0.0979		0.0974		0.0970	
Ratio	1.2897	1.2890		1.2980		1.3064	
Marginal tax rate							
Labour	0.1723	0.1725		0.1727		0.1730	
Capital	0.1455	0.1457		0.1452		0.1448	
Ratio	1.1841	1.1839		1.1893		1.1943	

Table B.7: Progressive consumption tax reform (cont.)

non HCA	Baseline	0.05, 0.05	% change	0.05, 0.10	% change	0.05, 0.15	% change
Aggregate							
Y	1.18	1.18	-0.2%	1.19	+0.1%	1.19	+0.5%
K	3.17	3.15	-0.4%	3.23	+2.0%	3.29	+3.9%
N	0.68	0.68	-0.1%	0.68	-0.9%	0.67	-1.4%
Avg. hours	0.33	0.33	-0.8%	0.33	-1.7%	0.33	-2.5%
w	0.93	0.92	-0.2%	0.93	+0.1%	0.93	+0.5%
r	0.052	0.052	+0.5%	0.049	-4.7%	0.047	-8.6%
beq	0.040	0.040	-0.4%	0.041	+0.7%	0.041	+1.9%
CEV		-0.07%		2.68%		5.12%	
Gini							
Consumption	0.34	0.34	+0.3%	0.33	-2.4%	0.32	-4.9%
Wealth	0.76	0.76	-0.05%	0.76	+0.1%	0.76	+0.2%
Average tax rate							
Labour	0.1259	0.1261		0.1263		0.1266	
Capital	0.0976	0.0977		0.0970		0.0966	
Ratio	1.2897	1.2916		1.3015		1.3097	
Marginal tax rate							
Labour	0.1723	0.1724		0.1726		0.1729	
Capital	0.1455	0.1455		0.1449		0.1445	
Ratio	1.1841	1.1853		1.1912		1.1961	

Appendix C

Appendix for Chapter 3

C.1 Markov Chain for Labour Productivity

The Markov chain governing idiosyncratic labour productivity for both education groups is given as follows:

Table C.1: Markov Chain for labour productivity

i,j	1	2	3	4	5	6	7
1	0.64699018	0.04869819	0.00366545	0.00027589	0.00002077	0.00000156	0.00000012
2	0.29218912	0.66531746	0.09849995	0.01105866	0.00110670	0.00010395	0.00000938
3	0.05498182	0.24624987	0.67643842	0.14858230	0.02215898	0.00276676	0.00031149
4	0.00551789	0.0368622	0.1981097	0.68016629	0.19810973	0.03686221	0.00551789
5	0.00031149	0.00276676	0.02215898	0.14858230	0.67643842	0.24624987	0.05498182
6	0.00000938	0.00010395	0.00110670	0.01105866	0.09849995	0.66531746	0.29218912
7	0.00000012	0.00000156	0.00002077	0.00027589	0.00366545	0.04869819	0.64699018
η_L	0.228	0.337	0.499	0.738	1.092	1.616	2.391
η_H	0.333	0.492	0.729	1.078	1.596	2.361	3.494

C.2 Tables

Table C.2: Optimal labour income tax function parameters

Tax Parameters	Baseline	NHC	NHC+DM	HC	HC+DM
λ_0	0.178	0.416	0.210	0.031	0.185
λ_1	2.617	2.238	1.705	4.537	2.489
λ_2	0.002	0.000	0.002	0.003	0.000

C.3 Figures

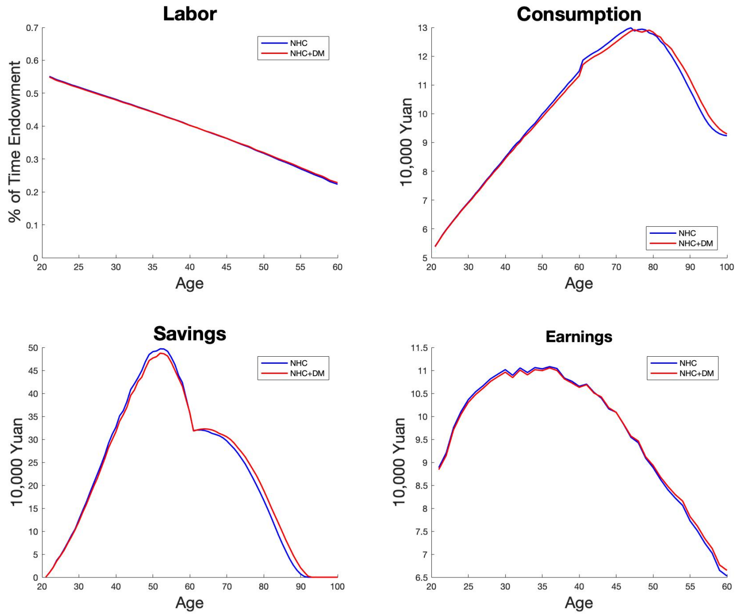

Figure C.1: NHC and NHC+DM Baseline life-cycle profiles

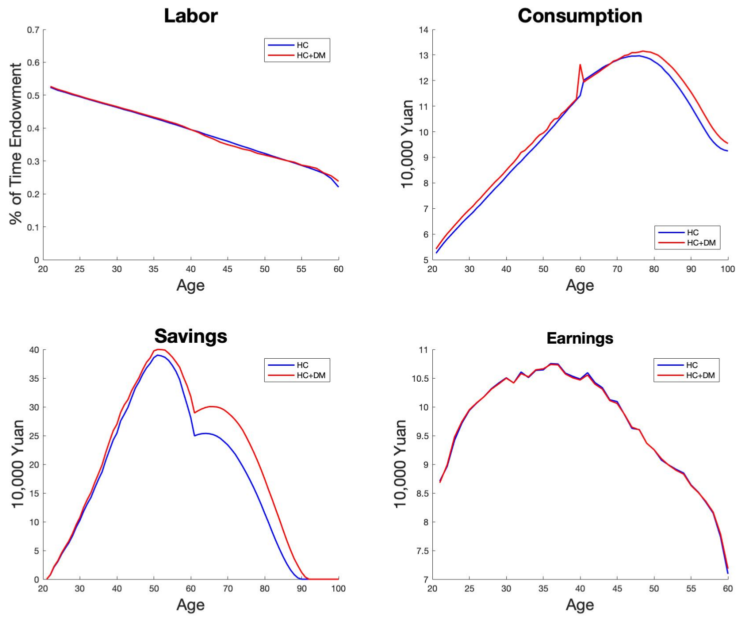

Figure C.2: HC and HC+DM Baseline life-cycle profiles

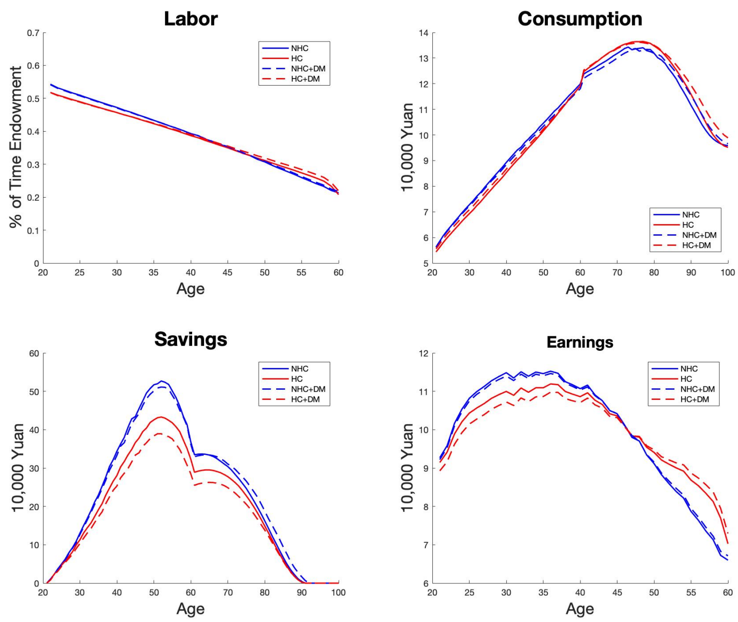

Figure C.3: NHC, HC, NHC+DM and HC+DM Optimal life-cycle profiles

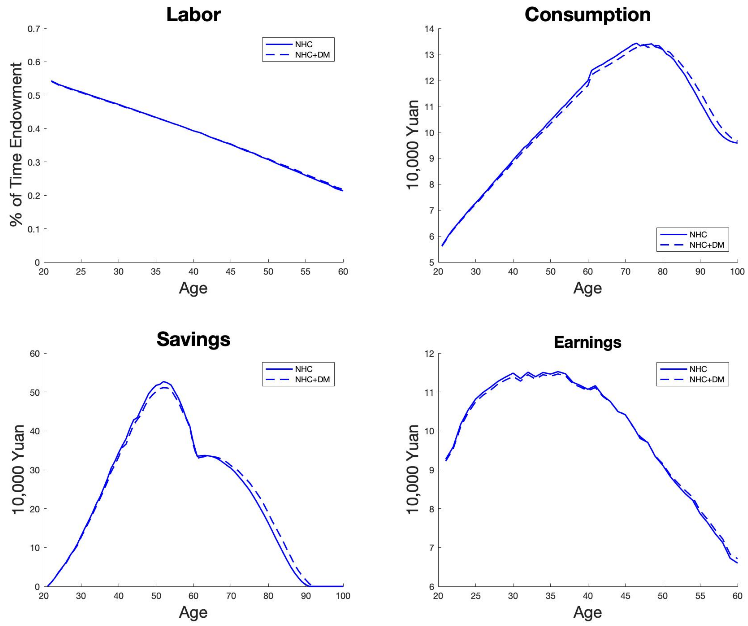

Figure C.4: NHC and NHC+DM Optimal life-cycle profiles

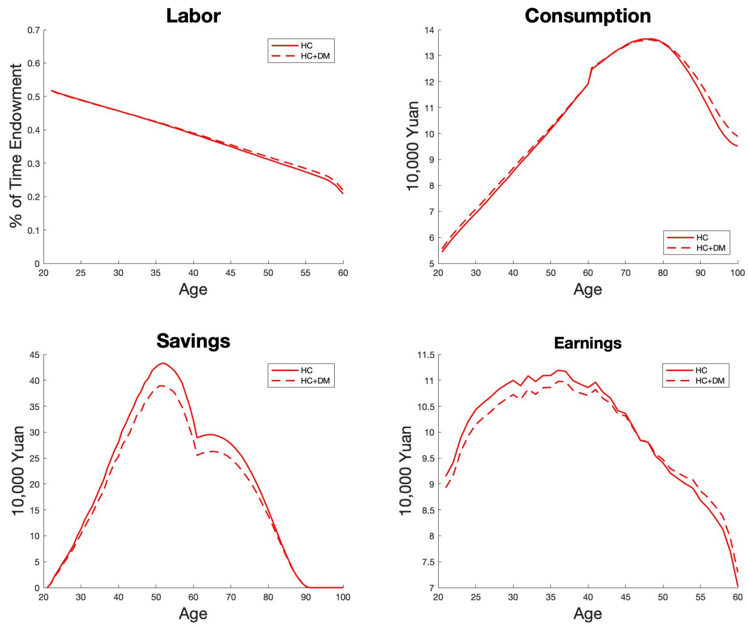

Figure C.5: HC and HC+DM Optimal life-cycle profiles

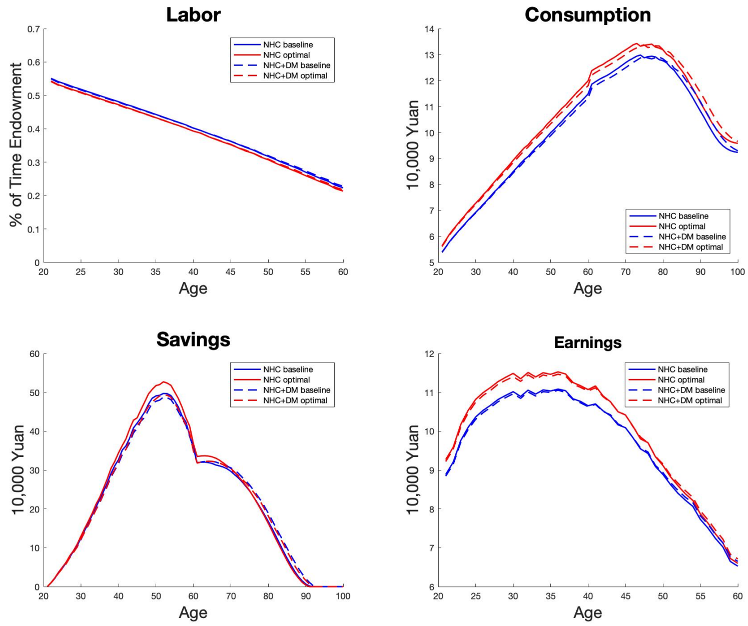

Figure C.6: NHC baseline and optimal, NHC+DM baseline and optimal life-cycle profiles

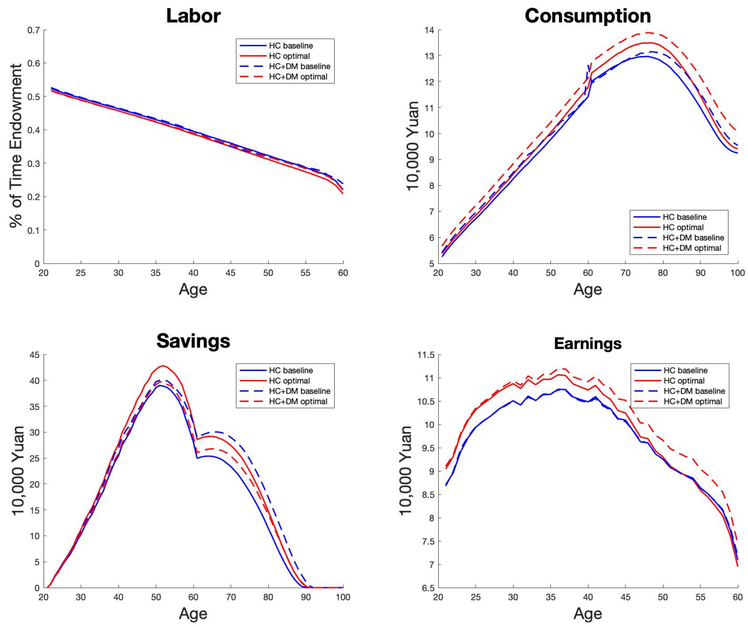

Figure C.7: HC baseline and optimal, HC+DM baseline and optimal life-cycle profiles

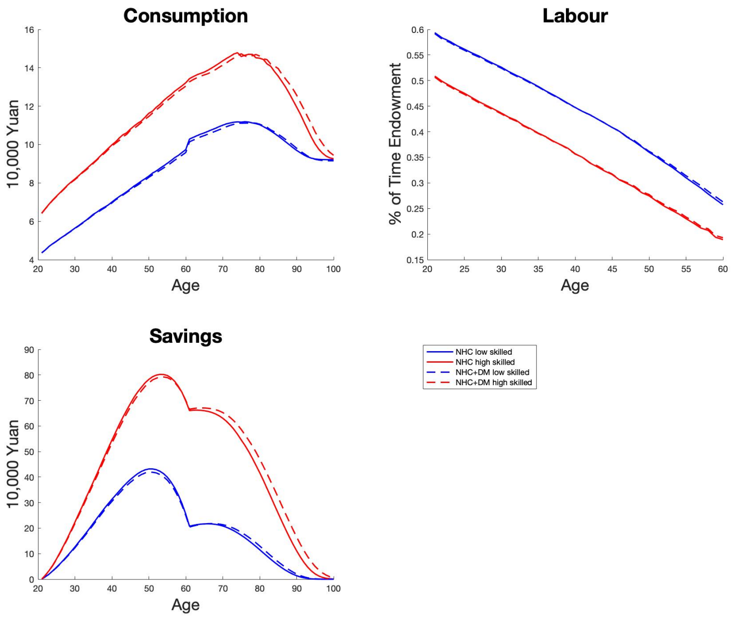

Figure C.8: NHC and NHC+DM baseline life-cycle profiles in different skilled groups

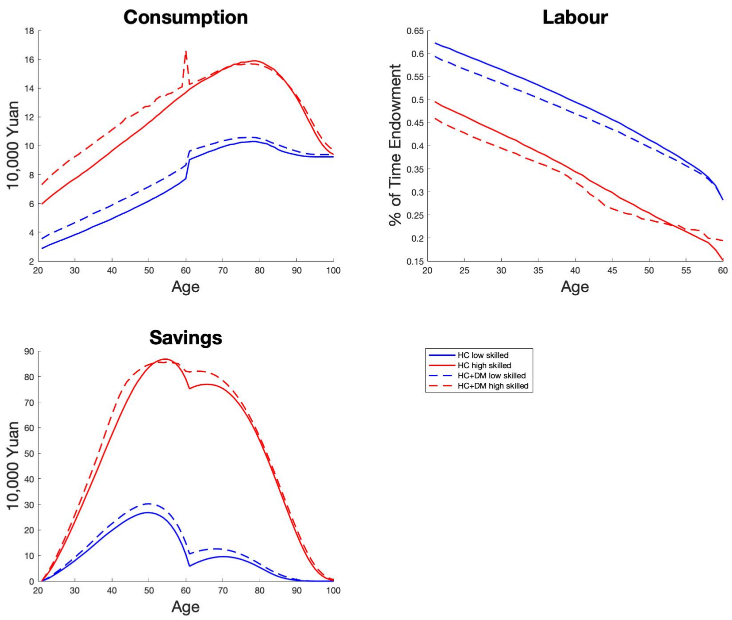

Figure C.9: HC and HC+DM baseline life-cycle profiles in different skilled groups

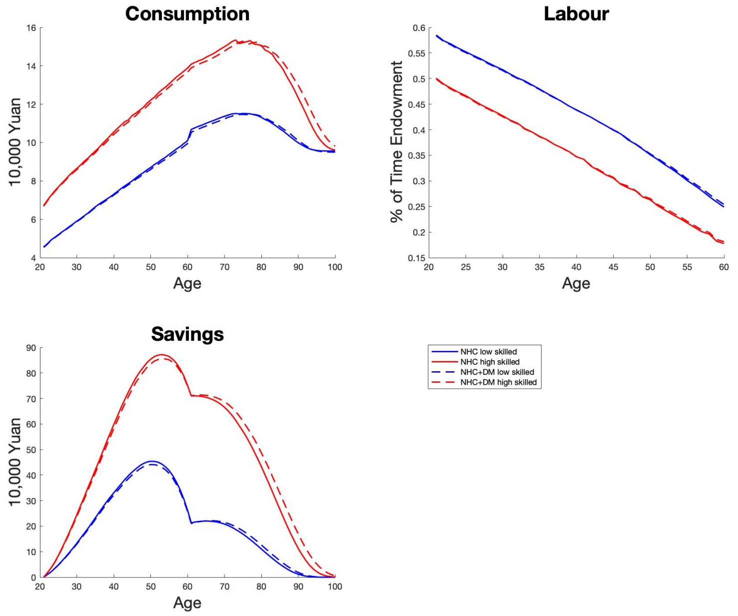

Figure C.10: NHC and NHC+DM optimal life-cycle profiles in different skilled groups

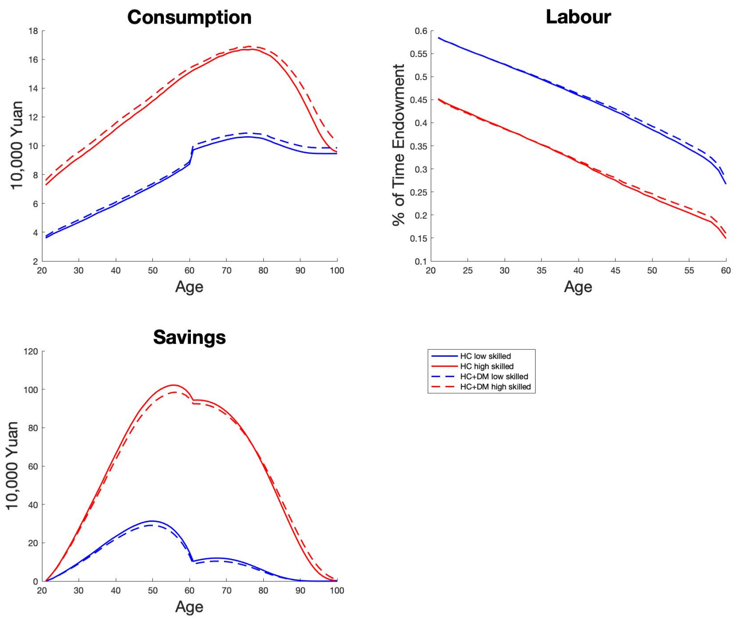

Figure C.11: HC and HC+DM optimal life-cycle profiles in different skilled groups

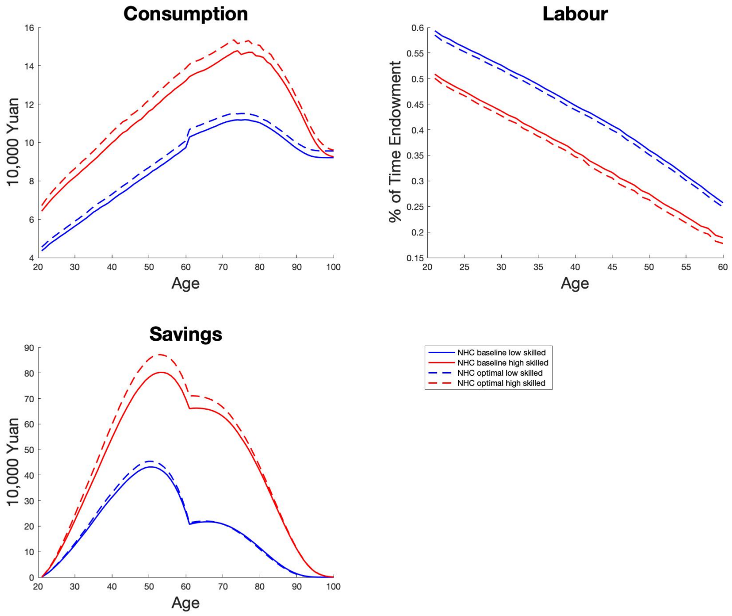

Figure C.12: NHC baseline and optimal life-cycle profiles in different skilled groups

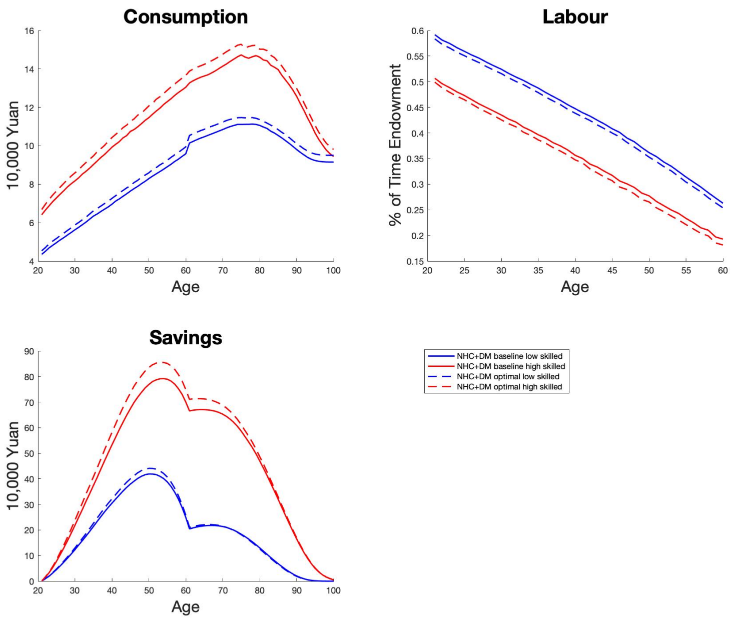

Figure C.13: NHC+DM baseline and optimal life-cycle profiles in different skilled groups

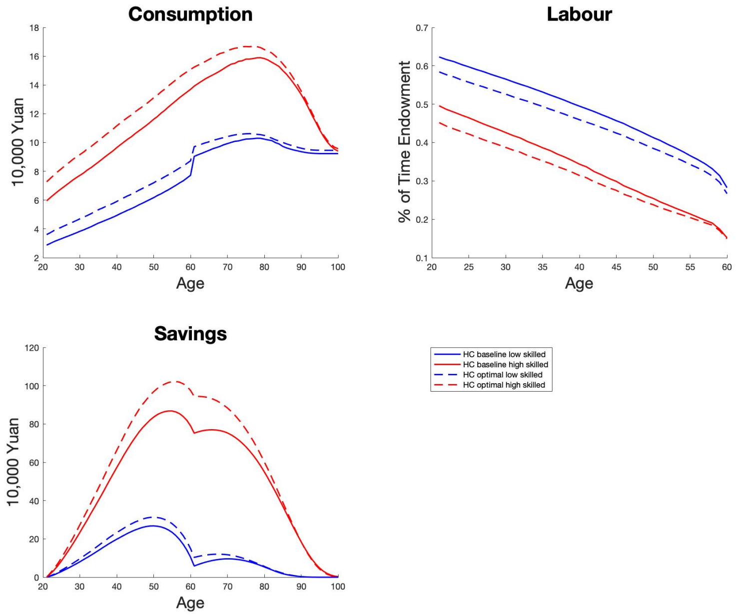

Figure C.14: HC baseline and optimal life-cycle profiles in different skilled groups

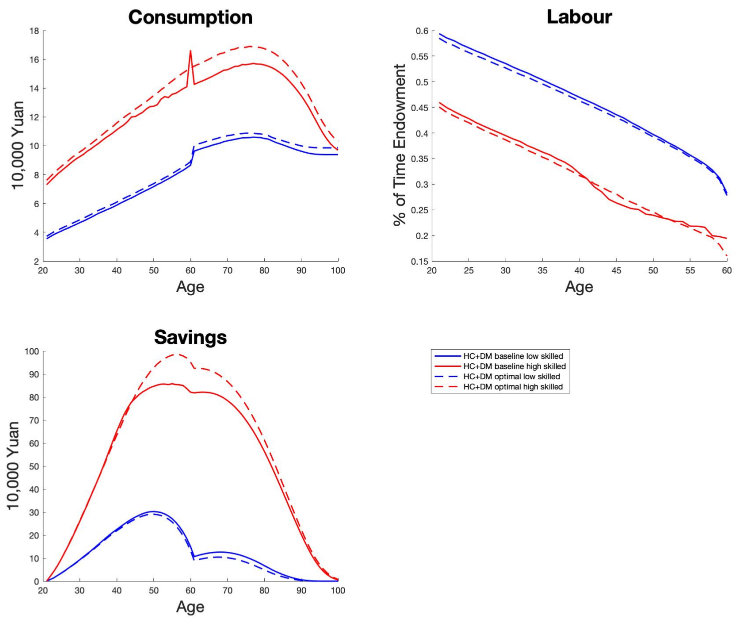

Figure C.15: HC+DM baseline and optimal life-cycle profiles in different skilled groups

Appendix D

Program Implementation

D.1 Code

Codes will be provided separately upon request due to the large size, including Fortran, Python, Matlab, and Stata.