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Aging, Health Risk, and Interest Rates

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Abstract

Over the past few decades, the Japanese economy has experienced a secular decline in the real interest rate, which is the return on safe and liquid assets. At the same time, the gap between the returns on liquid bond and illiquid capital (i.e., the risk premium) has increased because of the steady return on risky assets. This paper explores the role of the health risk in the increase in the premium, using a general equilibrium overlapping generations model. In the model, individuals are heterogeneous in health status and they incur medical costs. The model also features the presence of additional medical transaction frictions, which increase with medical expenditure but can be reduced by holding liquid assets. I find that both demographic aging and the increase in the individual out-of-pocket medical costs could push down the return on bond and lead to the widening premium. However, the latter effect is dominant because higher medical burdens encourage individuals to save more liquid bond rather than illiquid capital in order to mitigate the medical transaction frictions. According to these findings, the changes in the medical systems will continue to contribute to the further widening risk premium, although the future trend will be affected by several factors, not only medical systems but also demographics and government bond supply.

Keywords: Health Risk; Demographic Aging; Risk Premium; Overlapping Generations

JEL classification: E21, G51, I10, J11

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1 Introduction

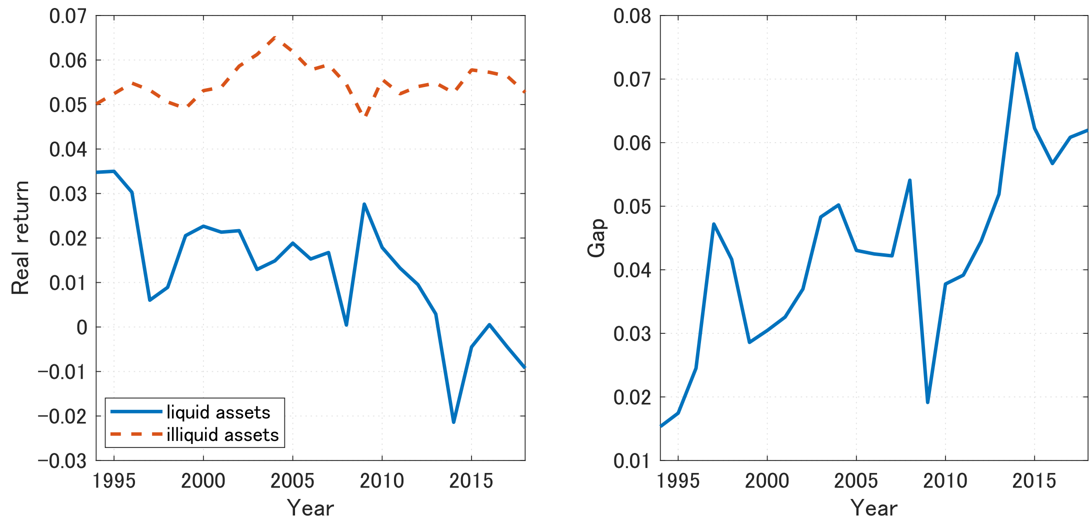
In the most advanced countries, including Japan, the real interest rate on liquid assets like deposits and bonds has declined over the past few decades. This drop in the interest rate, called "secular stagnation" in Rachel and Summers (2019), has been recently refocused attention and concerned, mainly because it could increase the risk of asset bubbles and limit the effectiveness of the monetary policy. On the other hand, the real return on illiquid assets like stocks and capital has remained stable or increased slightly.

Figure 1 shows the trends in the returns on liquid assets and illiquid assets in Japan. Here, the return on liquid assets represents the real interest rate on 10-year bonds, which is calculated by subtracting CPI inflation rate from the nominal 10-year bond rate. The return on illiquid assets is calculated by dividing the real operating surplus by total illiquid assets, including financial stocks and non-financial fixed assets. As seen in the left panel of the figure, while the return on bond has largely dropped from 3.5% in 1994 to -0.1% in 2018, the return on capital has little changed from 5.0% in 1994 to 5.3% in 2018. The difference in these trends has brought about an increasing gap between the two rates (i.e., risk premium). The right panel of Figure 1 shows that the risk premium has widened significantly from 1.5% in 1994 to in 2018. What is behind the expansion of the risk premium? Will the trend of the secular decline in the return on bond and the increase in the premium continue in the future? The main purpose of this paper is to answer these questions.

This paper quantitatively investigates the impact of changes in the economic structures, including demographics and health care systems, on the returns of liquid and illiquid assets and the return gap, using a dynamic general equilibrium model of overlapping generations. In particular, as discussed below, the novelty of the paper is to focus on the relationship between health or medical expenditure risk and the gap between the two asset returns.

The potential drivers behind the secular decline in the real interest rate have been the subject of a lot of research. Many papers, including Carvalho et al. (2016), Lisack et al. (2017), Cooley and Henriksen (2018), Eggertson et al. (2019), Gagnon et al. (2021), and Papetti (2021), develop macroeconomic models, such as overlapping generations models, and show that demographic aging can explain most of the decline. The mechanism of low interest rates through demographic channels is as follows. First, the increased longevity encourages household to save. In addition, the change in population distribution increases the old-age population with higher savings. These lead to

Figure 1: Returns on Liquid Bond and Illiquid Capital (Left Panel) and the Gap (Right Panel) in Japan



an increase in the aggregate capital stock. Second, due to lower fertility, the shrinking working-age population causes the decline in the aggregate labor supply. The rise in the capital-labor ratio is driven by these two forces and it results in a decline in the marginal productivity of capital and the real interest rate. To explore different channels, other papers focus on the rise in income and wealth inequality (Straub, 2019; Auclert and Rognile, 2020; Mian et al., 2021), the decline in the price of the investment goods (Eichengreen, 2015; Sajedi and Thwaites, 2016), and the rising market power and intangibles (Farhi and Gourio, 2019).

However, almost all of these models assume an economy with a single rate of return. In other words, they do not explicitly distinguish between government bonds and capital and assume that the two assets have the same rate of return. In the models without aggregate uncertainty, both the marginal productivity of capital and the interest rate fall, because the arbitrage condition holds such that the real interest rate equals to the net rental rate of capital (which is the marginal productivity of capital minus the depreciation rate). This is inconsistent with the findings, observed in Figure 1, that the real interest rate has dropped but the return on capital has not declined at all.

Some recent papers use general equilibrium overlapping generations models with two types of assets, liquid bond and illiquid capital, and address the explanation of the gap between the two asset returns. They try to reproduce the aggregate demand for liquid assets by introducing a preference for bonds (Muto et al., 2016; Sudo and Takizuka,

2020) or various shocks, such as stochastic capital depreciation (Gomes and Michaelides, 2008), idiosyncratic income risk (Aladangady et al., 2021), idiosyncratic risk on capital (Brunnermeier et al., 2022), and aggregate productivity shock (Kopecky and Taylor, 2022). These ideas are based on the global savings glut and agents' precautionary saving for liquid or safe assets to insure themselves against shocks, discussed in the papers by Caballero et al. (2016, 2017) and Caballero and Farhi (2018).

For example, Aladangady et al. (2021) find that the greater polarization of household labor income has contributed to the widening gap between the risk-free rate and the return on capital in the U.S., using an overlapping generations model with labor income risk. Kopecky and Taylor (2022) build a two-asset heterogeneous agent life-cycle model and find that, in the economy with aggregate risk, aging demographics can simultaneously reproduce the falling risk-free rate and the increasing risk premium. This paper also explores the potential drivers of the increasing risk premium as in these literature, but I focus specifically on the idiosyncratic health shock and the medical expenditure shock. This is motivated by Japanese data on household saving behavior and the empirical evidence on the relationship between household asset portfolio and health.

In Japanese household level data, older household over age 70 still have higher asset holdings, especially in the form of liquid assets rather than illiquid assets. In addition, many households have large savings to prepare for health risks and are concerned about their old lives due to the increase in out-of-pocket costs for medical care and long-term care. On the other hand, some empirical evidence shows that poor health causes households to prefer holding safer assets rather than risky assets (Rosen and Wu, 2004; Christelis et al., 2005; Goldman and Maestas, 2013).[1] Atella et al. (2012) and Goldman and Maestas (2013) find that individuals' health insurance status also affects their holdings of risky assets. These facts would imply that health uncertainty and the existence of the individual medical burden work as potential drivers of high demand for safe assets and the low asset return. Thus, in the paper, I build the large-scale, general equilibrium overlapping generations model with health shock and show quantitative results that both the decline in the bond return and the widening risk premium can be reproduced by structural changes in demographics and medical systems.

First, I present the two-period, partial equilibrium, model and provide analytical

[1]Love and Smith (2010) find that there is no longer a statistically significant relationship between health measures and household portfolio decisions, if unobserved household heterogeneity is adequately taken into account.

results that health or medical expenditure risk could induce household demand for liquid assets and lead to a positive difference between the returns on liquid and illiquid assets (risk premium). The model has three features. First, individuals choose the portfolio of two types of assets: liquid bond and illiquid capital. Second, individuals face a health risk and, if they get poor health, they incur medical costs. Finally, individuals have to pay for the additional transaction costs associated with medical care. These costs, which include not only pecuniary but also non-pecuniary (e.g., psychological) costs, increase with the amount of medical expenses but decrease with the asset holdings of liquid bond. Under these assumptions, I show that individuals have a precautionary saving motive for liquid bond to prepare for the health risk. It generates bond demand, despite its lower return, and leads to the positive premium. When the health risk or medical expenditure increase, the bond demand also increases, leading to a decline in the equilibrium bond return and an expansion of the risk premium.

Next, to quantitatively explore the role of health or medical expenditure risk on the bond return and the risk premium, I extend the model to a general equilibrium setting, populated by long-lived individuals who differ in their age, labor productivity, capital depreciation, wealth, and health status. In the model, individuals choose consumption, labor supply, and bond and capital holdings, and need to pay for medical care, using labor income, capital income, bond income, pension benefits, and means-tested transfers. When consuming medical goods, individuals also incur medical transaction costs. The representative firms produce output by using capital and labor inputs. The government issues new government debt and taxes consumption, labor income, bond income, and capital income to finance government expenditure, interest payments on its debt, pension benefits, medical benefits, and a transfer. I calibrate the model by using micro and macro variables of the Japanese economy in 2014, and examine the effects of population aging and the presence of health risk and medical expenditure on macroeconomic variables.

My quantitative results are as follows. First, using the life-cycle model with health risk and medical transaction costs, I reproduce well the past changes in the bond return and the risk premium over these several decades. In the real economy, the post-tax return on bond has decreased by 2.4% from 2.8% in 1990 to 0.4% in 2014. The post-tax premium has increased by 2.7% from 0.2% in 1990 to 2.9% in 2014. In contrast, the post-tax bond returns in the model were 3.0% in 1990 and 0.4% in 2014. These values are very close to the real values. On the other hand, in the model, while the post-tax premium was 0.9% in the 1990 economy, it was 2.4% in the 2014 economy. Thus, the difference between the two steady state economies is 1.5%, which is positive but smaller than the real value of 2.7%. This is because the decline in the return on capital due to population aging is much larger in the model than in the real economy.

Second, the increase in the risk premium has been mainly driven by medical structural changes, such as the increase in per capita medical spending and the raised copayment rates, rather than by demographic aging. Population aging has increased both aggregate liquid bond and illiquid capital, leading to a decline in the returns on these assets. While the post-tax capital return has declined by 1.3% from 1990 to 2014, the post-tax bond return has declined by 1.6% from 1990 to 2014. Thus, demographic changes contribute to the premium increase by only 0.3% from 1990 to 2014. The remaining increase by 1.2% (=1.5%-0.3%) is explained by medical structural changes. The increase in out-of-pocket copayments has reduced only bond return, because it has promoted individuals to hold more liquid bond to mitigate medical transaction costs. While the post-tax capital return has increased by 0.2% from 1990 to 2014, the post-tax bond return has decreased by 1.1% from 1990 to 2014. Hence, there is significant downward pressure on the bond return and upward pressure on the risk premium.

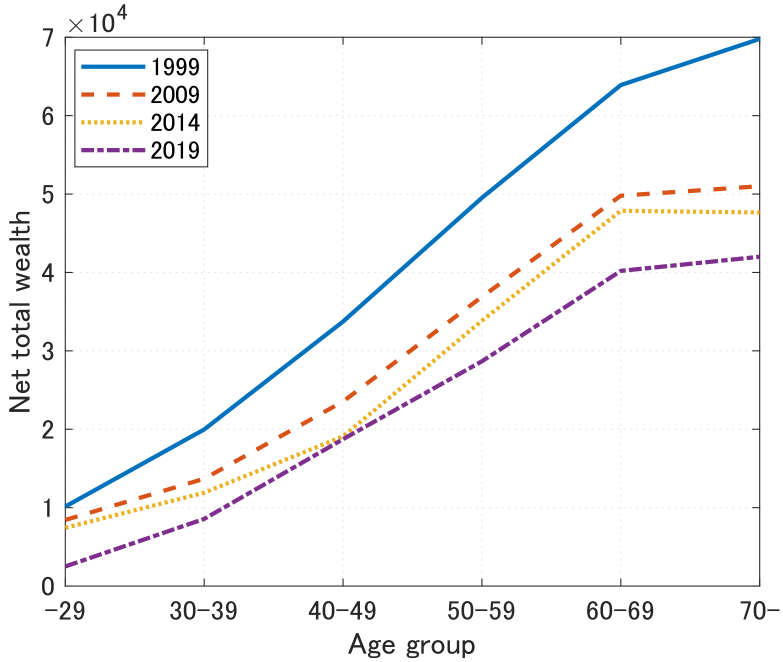
Third, the future trend of the premium depends on the future economic conditions, including demographic dynamics, medical systems, and the government debt. The aging of the population and the increase in the individual medical burden will lead to a decline in the return on bond and an increase in the risk premium. However, rising government debt will place the upward pressure on the bond return, leading to the smaller premium. If the former effect dominates (is dominated by) the latter effect, the premium will continue to increase (decrease in the opposite direction) in the future.

The rest of the paper is organized as follows. Section 2 provides an overview of household saving behavior in Japan. Section 3 presents its analytical results using a simple two-period model. Section 4 builds a dynamic, stochastic, general equilibrium, overlapping generations model. Section 5 calibrates the model to the Japanese economy. Section 6 reports the numerical results and quantitatively compares aggregate features under different steady states, and concluding remarks are given in Section 7.

2 Japanese Household Saving Behavior

In this section, I review of the characteristics of the total wealth and asset portfolio of Japanese households over the life-cycle, by using data from the National Survey

Figure 2: Net Total Wealth by Age Group in Japan



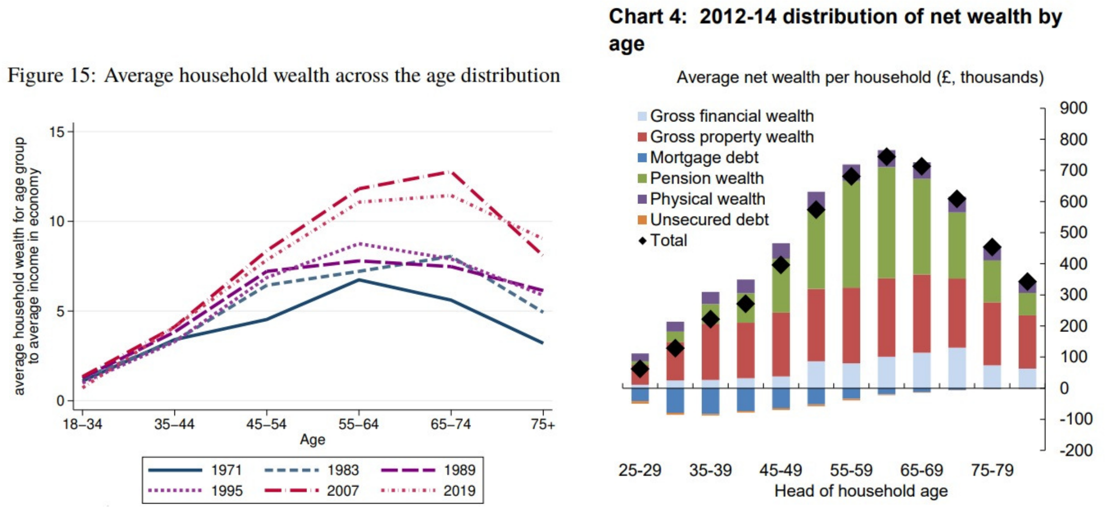
of Family Income and Expenditure (NSFIE) and from the Public Opinion Survey on Household Financial Assets and Liabilities (hereafter, I call SHFAL). NSFIE has been conducted every five years since 1959 and provides detailed information on household consumption, income, and wealth by age group or region. SHFAL is the survey conducted annually since 1963 by the Central Council for Financial Services Information of the Bank of Japan. This survey provides the information on household's current status and plans regarding financial savings and liabilities.

2.1 Total Wealth over the Life-Cycle

Figure 2 shows the net total wealth of households by age group using data from the 1999, 2009, 2014, and 2019 NSFIE. Here, net total wealth is the sum of net liquid assets, subtracting liabilities from gross liquid assets, and illiquid assets which include real estate. First, gross liquid assets include cash, deposits, bond, and money trusts, and liabilities include all borrowing such as housing loans and installment.[2] Second, gross illiquid assets include both financial and real assets. Financial assets include stock and life insurances, and real assets include land, housing, and consumption of durable

[2] I assume that all loans are assigned to liquid assets.

Figure 3: Net Total Wealth by Age Group in the U.S. (Left Panel) and UK (Right Panel)

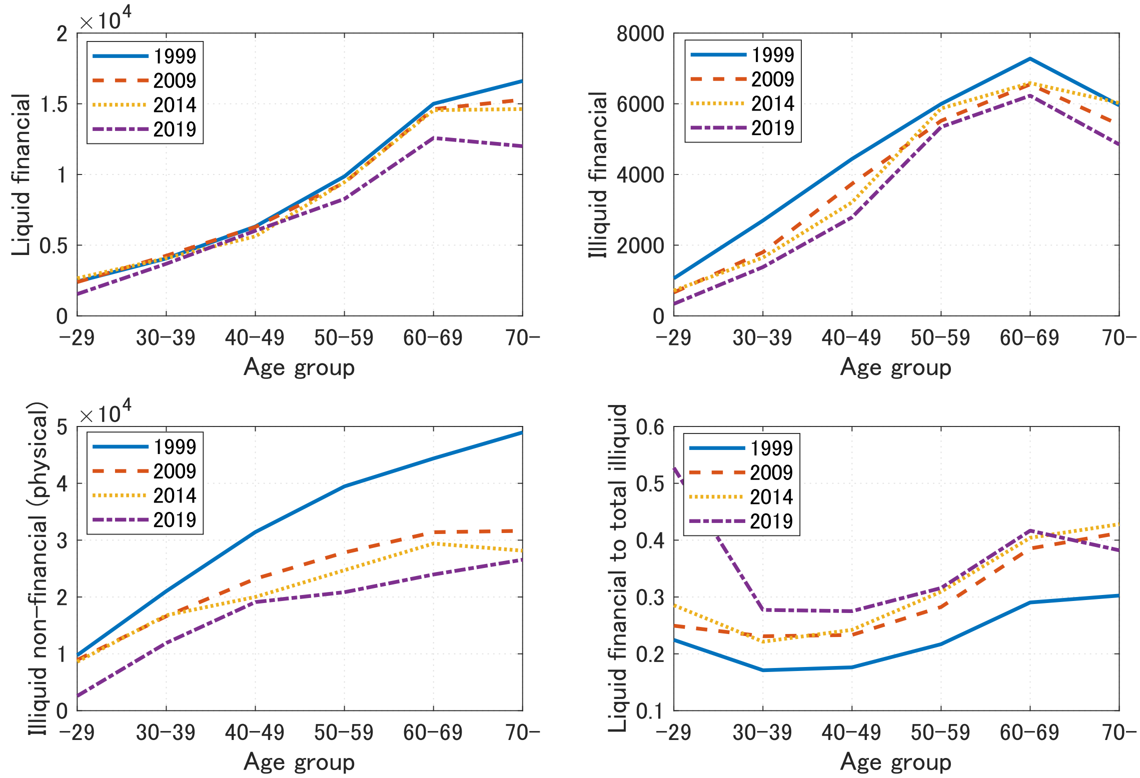


Notes: While the left panel shows the average wealth over the life-cycle of U.S. households, the right panel shows the distribution of net wealth by age for UK households.
Sources: Left panel, based on data from the Survey of Consumer Finances Plus (SCF+), is taken from Mian et al. (2021), and right panel, based on data from the Wealth and Asset Survey (WAS), is taken from Haldane (2018).

goods. This classification into liquid and illiquid assets follows Kaplan et al. (2018) and Braun and Ikeda (2021). In the following section 2.2, I use this specification again.

As seen from Figure 2, total wealth increases monotonically with age in all years. In particular, households continue to hold larger assets after the age of 70. Indeed, these properties are distinct in Japan, which is not observed in the other advanced countries including the U.S. and UK. Figure 3 reports the average household net wealth by age. The left and right panels show household asset holdings in the U.S from Mian et al. (2021) and UK from Haldane (2018), respectively. In both countries, households increase their wealth with age, but begin to withdraw it after age 60 or 65. Such hump-shaped patterns of savings are consistent with the life-cycle hypothesis developed by Modigliani and Brumberg (1954). Next, in order to further discuss the point that Japanese households tend to have higher wealth in their old ages, I look at each type of asset, liquid and illiquid, of households by age in Japan.

Figure 4: Liquid and Illiquid Wealth by Age Group in Japan



2.2 Liquid and Illiquid Wealth by Age

Figure 4 shows the liquid and illiquid wealth of households by age group using data from the 1999, 2009, 2014, and 2019 NSFIE. There are four panels in the figure: the top left panel of liquid financial assets, the top right panel of illiquid financial assets, the bottom left panel of illiquid real or physical assets, and the bottom right panel of the ratio of liquid financial assets to illiquid total assets (=financial+physical). My strategy for classifying assets into liquid and illiquid is already mentioned above. First, we can see that all types of assets show an upward trend with age. However, only illiquid financial assets decline slightly after the age of 70. Second, the ratio of liquid to illiquid assets increases with age. For example, while the ratio is 0.22 in the 30-39 age group, it is 0.31 and 0.43 in the 50-59 and 70- age groups, respectively. Thus, Japanese households still have very high levels of wealth in old age, especially in the form of the liquid assets. Why do older households hold more assets without reducing their wealth? Why do they prefer for liquid assets to illiquid assets? Finally, to consider these questions, I briefly summarize the results of the SHFAL questionnaire on households' motive and plan for savings.

2.3 Reasons behind Japanese Household Savings

I here discuss the potential reasons for the financial asset holding behavior of households, especially the elderly, from the 2014 SHFAL. There are four key facts from the data. First, the common reasons for older households' savings are "for old lives" and "for risks of unanticipated disaster and illness". For younger people under 40s, the most common reason for their savings is "for children's education" and the second common reasons is "for risks of unanticipated disaster and illness". For example, while the first reason is supported by 67.6% of households of age 40s, the second reason is supported by 52.3% of households.[3] However, as people get older, they are more likely to have savings from the reason "for old lives"; 84.0% (79.8%) of households of age 60s (or over 70) support this reason, compared to 51.0% of households of age 40s. In addition, more people in old age support the reasons "for risks of unanticipated disaster and illness". Many older people, 69.1% (74.6%) of households of age 60s (or over 70) answer that they save to prepare for the disaster or health risk.

Second, on average, 82.7% of Japanese households have concerns about their lives after the retirement. In addition, half of them answer that they are "very" worried about their old lives.

Third, on average, almost all households (94.5%) answer that pension income is not enough for their lives. Their most common reason is "because they believe that pension benefits will be cut" and 63.4% of households support this reason. Note that 48.4% of households in total support the reason that "because individual burden for medical and long-term care will increase".

Fourth, young and old people have different criteria for determining the asset portfolio. Regardless of age, the safety is the most important factor in selecting assets. However, while younger households value the profitability of asset holdings, older households value the liquidity rather than profitability. For example, 18.7%, 44.5%, and 21.0% of households of age 30s, prefer the profitability, safety, and liquidity, respectively. In contrast, these persentages are 15.8%, 41.9%, and 30.6%, respectively, for households of age 60s.

These facts, mentioned in Sections 2.1-2.3, would imply that Japanese elderly people

[3] In the survey, households can answer at most three reasons for their savings.

have a high level of wealth, especially in the form of safe and liquid assets, to prepare for the risk of health and medical expenses. This relationship is consistent with the findings of several empirical papers, including Rosen and Wu (2004), Christelis et al. (2005), and Goldman and Maestas (2013), that health condition and medical risk cause households to rebalance their portfolios away from risky assets and towards safer assets.

Thus motivated, in the next section, I start with a simplified theoretical model framework and reproduce the relationship between health or medical expenditure risk and demand for safe assets, by introducing a transaction cost mechanism which is the feature of the paper.

3 Two-Period Model

This section presents a simple two model and provides the economic intuition behind the role of health or medical expenditure risk on the demand for liquid assets and the gap between the returns of liquid and illiquid assets. In particular, the model focuses mainly on the liquid asset holdings to prepare for health or medical expenditure risk, the positive gap between liquid and illiquid asset returns (i.e., risk premium), and the impact of health-related risk on the size of the premium, and shows its analytical results.

In the model, households live for two periods. They are young in the first period and become old in the second period. In the first period, individuals are endowed with income y. They choose consumption $c_1$and savings, using the income. They can save in two forms of assets, liquid and illiquid. While liquid assets, denoted by b, include money and bond, illiquid assets, denoted by k, include equity and capital. Both asset holdings yield positive returns, but I assume that the return on illiquid capital S is equal to or higher than the return on liquid bond R ($S \geq R$). Hence, the illiquid capital has an advantage over the liquid bond, in the sense of a higher return. In the second period, individuals have no income endowment and receive interest income from their asset holdings. Households face a health risk and they get one of two health states, good g or poor p, when they enter the second old period. The probability of getting bad health is ϕ and individuals know the probability in their first young period. If individuals have good health, they choose consumption c_2^g. On the other hand, if individuals have bad health, they choose consumption c_2^p and have to pay for medical care $m\,(> 0)$.

Here, I assume that individuals incur additional transaction costs tc when paying for medical care. Importantly, this transaction friction represents all potential indirect costs associated with medical care, including pecuniary and non-pecuniary (e.g., psychological) costs. The former monetary costs are additional costs for visits to medical institutions and procedures for medical care or hospitalization. On the other hand, the latter psychological costs are mental distress or anxiety due to illness and the need for medical treatment. The transaction costs are given as

$$tc = \varepsilon \left[\frac{m}{\exp(b)} \right], \tag{1}$$

where ε is the parameter of the severity of the transaction friction. Here I discuss the two important properties of this cost function, although the transaction costs have several other properties.[4] First, when medical spending m increases, costs tc become larger (i.e., $\partial tc/\partial \lambda m \geq 0$). Second, when liquid bond holdings b increase, costs tc become smaller (i.e., $\partial tc/\partial b \leq 0$). The second property is particularly important in this paper. By holding a more liquid bond, individuals can mitigate the transaction costs associated with medical spending. This advantage of liquid bond in terms cost reduction promotes households to hold liquid assets with lower return.

The formation of transaction friction (1) is very similar to shopping cost or time technology in the monetary theory, as in Attanasio et al. (2002), Gavin et al. (2007, 2015), and Aoki et al. (2021). In their models, they assume that shopping costs or time in purchasing consumption goods can be reduced by holding money or cash, because these assets are more liquid. In my paper, the mechanism for generating demand of liquid assets is the same as in these monetary models. However, as mentioned above, the transaction costs of medical spending (1) also include psychological costs. The costs partially capture the aspect that holding liquid bonds to prepare for health risk events would reduce the individual's psychological anxiety or depression about their health and medical costs. If individuals anticipate that they will need a large amount of money in the future due to illness or hospitalization, they are likely to feel a great deal of psychological anxiety, even if they do not have to pay any pecuniary costs for associated events such as hospital visits and procedures for hospitalization. In order to reduce the psychological costs due to such health or medical expenditure uncertainty,

[4] Other properties of transaction costs are as follows. First, when medical spending is zero, there is no transaction friction (i.e., $tc = 0$ if $m = 0$). Second, costs increase as medical spending increases, and the marginal increase in costs rises with medical spending (i.e., $\partial^2 tc/\partial (m)^2 \geq 0$). Third, the marginal decline in costs from holding bonds diminishes when bond holdings become larger (i.e., $\partial^2 tc/\partial (b)^2 \geq 0$). Finally, the marginal transaction cost of additional medical spending does not increase with bond holdings (i.e., $\partial^2 tc/(\partial \lambda m \partial b) \leq 0$).

it would be natural that individuals have an incentive to hold liquid assets that can be easily liquidated.

The household's utility maximization problem is defined as follows.

$$\max_{c_1, c_2^g, c_2^p, b, k} u = c_1 + \beta \left[(1-\phi) \log \left(c_2^g \right) + \phi \log \left(c_2^p \right) \right], \tag{2}$$

subject to

$$c_1 + b + k = y, \tag{3}$$

$$c_2^g = Rb + Sk \qquad (\text{w.p.} 1-\phi), \tag{4}$$

$$c_2^p + m + tc = Rb + Sk \qquad (\text{w.p.} \phi), \tag{5}$$

where β is a subjective discount factor. Using the first-order conditions, we obtain

$$S - R = \left(\frac{\beta \phi S}{c_2^p} \right) \left[\frac{\varepsilon m}{\exp(b)} \right] \geq 0. \tag{6}$$

The above equation (6) represents the return gap between liquid and illiquid assets (risk premium). This positive premium is generated by the transaction frictions, since the model produces zero premium when the severity parameter ε is zero. The risk premium increases with higher values of (i) the parameter ε, (ii) the health risk ϕ, (iii) the amount of medical expenditure m, and (iv) the discount factor β. These properties imply that the demand for liquid debt is maintained despite its lower return, when (i) there is a stronger benefit of lower transaction friction from holding liquid bond, (ii&iii) individuals have a larger expected medical burden, (iv) individuals value the second old period more.

Now, the demand for liquid bond is defined as

$$b = \log \left[\frac{-\varepsilon \left\{ (1+\beta) S - R - m \right\} + \varepsilon \sqrt{\left\{ (1+\beta) S - R - m \right\}^2 + 4m \left\{ (1+\beta\phi) S - R \right\}}}{2 (S - R)} \right]. \tag{7}$$

In order to analyze the role of health on bond demand, I take the derivatives of the demand with respect to health risk and medical expenditure as follows:

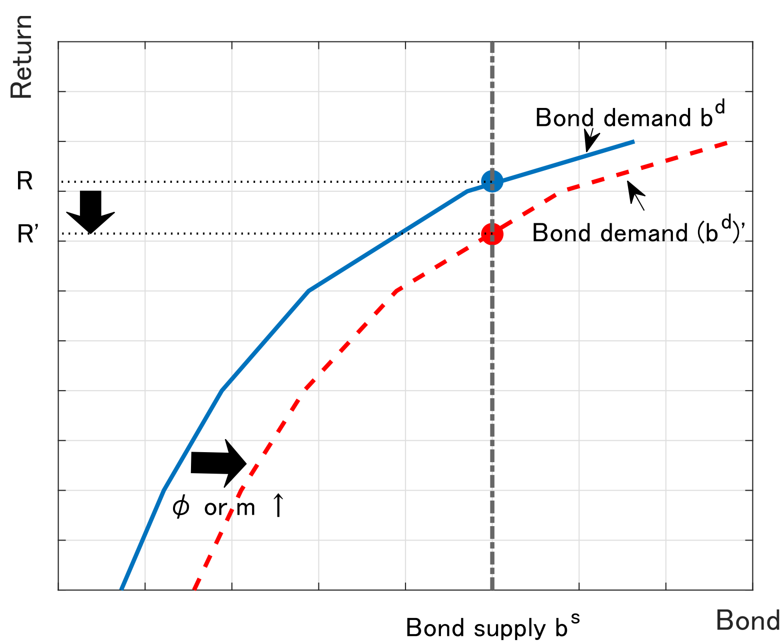
$$\left(\frac{\partial b}{\partial \phi} \right) > 0, \tag{8}$$

$$\left(\frac{\partial b}{\partial m} \right) > 0. \tag{9}$$

Equations (8) and (9) show that higher expected medical costs ϕm in old age lead to more liquid bond demand because holding bonds can mitigate the medical transaction costs.

Finally, consider the relationship between health, bond demand, and return on bond. Figure 5 shows the determination of the equilibrium interest rate in the model. Here, I assume that the supply of bonds b^s is fixed by the governments, and the demand for bonds, as shown in equation (7), is denoted by b^d. When the health risk ϕ or medical expenditure m increase, the bond demand curve shifts to the right, given the bond return R. Under the exogenous bond supply b^s, the equilibrium bond return falls. Thus, the mechanism of transaction friction (1) generates the negative relationship between health or medical expenditure risk and bond return.

Figure 5: Heath Risk and Bond Return



4 A Quantitative General Equilibrium Model

In this section, based on the two-period model in the previous section, I develop a general equilibrium model of overlapping generations with intra-generational heterogeneity in income, wealth, capital returns, and health status. The model features two types of assets (liquid and illiquid) and focuses on individuals' decisions to hold these assets over the life-cycle. While liquid assets b includes cash and bond, illiquid assets k include equity and capital. Importantly, I also incorporate the transaction cost of medical spending tc to capture the relationship between health risk and savings portfolios. These settings allow us to quantify the impact of demographic and medical structural changes on the return of liquid assets and the risk premium. I abstract the notation of the time period in the model because the paper focuses mainly on the steady states of the economy.

4.1 Demographics and Health Status

Time is discrete and one period corresponds to a year. The economy is populated by overlapping generations of individuals of model age $j = 1, 2, \cdots, 80$. Individuals enter the economy with no initial assets at actual age 21 ($j = 1$) and retire at age 65 ($j_r + 1 = 45$). The size of new cohorts grows at rate n. There is no aggregate risk in the economy, but individuals face idiosyncratic uncertainty regarding their health status. At age j, an individual health status h_j can be either "good" ($h_j = g$) or "bad" ($h_j = b$), and the health status evolves via a Markov chain $\Pi(h_j, h_{j+1})$. Individuals also face mortality risk and the maximum age is 100 ($j_f = 80$). Let ψ_j denote the probability that an individual of age j survives to the next age $j + 1$. The survival probability of age j_f is zero, that is, $\psi_{j_f} = 0$.

4.2 Uncertainties Regarding Labor Income and Capital Return

In addition, there is an idiosyncratic uncertainty about their individual labor productivity. The labor productivity η_j of age j evolves stochastically according to a Markov chain $\Pi(\eta_j, \eta_{j+1})$. Individuals are endowed with one unit of time that can be allocated for work and leisure. During the working period, earnings are given by $w\eta_j e_j l_j$, where w is the wage rate and l_j is hours worked at age j. In addition, e_j is a labor efficiency profile of age j. Following Aladangady et al. (2021), I assume that the the return on capital also has an idiosyncratic risk as follows.

$$r_j^k = MPK - \bar{\delta} - \delta_j, \tag{10}$$

where r_j^k is the return on illiquid capital k and MPK is the marginal productivity of capital. The depreciation rate of capital is denoted by δ. In particular, $\bar{\delta}$ is the average depreciation which is the same for all individuals, and δ_j is the stochastic depreciation of age j, which evolves via a Markov chain $\Pi(\delta_j, \delta_{j+1})$. Individuals can partially insure themselves against idiosyncratic risks to health, labor productivity, and capital returns by accumulating precautionary savings.

4.3 Preferences

Individuals choose consumption c_j and leisure $1 - l_j$ in each period, which bring utility:

$$u(c_j, l_j) = \frac{\left[c_j^{\sigma}(1 - l_j)^{1-\sigma}\right]^{1-\gamma}}{1 - \gamma}, \tag{11}$$

where σ is a consumption share in utility and γ is the relative risk aversion.

To summarize, individual's expected lifetime utility is given by

$$U = \mathbb{E}\left[\sum_{j=1}^{j_f} \beta^{j-1}\psi_j u(c_j, l_j)\right], \tag{12}$$

where $\mathbb{E}$ is the expectation operator and β denotes a subjective discount factor.

4.4 Transaction Cost of Medical Spending

Individuals also have to pay medical spending $m_{j,h}$, depending on their age and health status. The amount of medical spending is totally exogenous, and individuals in poor health incur more medical expenditure than healthy individuals. However, a fraction, $1 - \lambda_j$, of the medical spending is covered by the government. The actual medical costs faced by individuals are only $\lambda_j m_{j,h}$ and λ_j represents the copayment rate at age j.[5]

I assume that individuals incur additional transaction costs when paying for medical care, as in the two-period analysis in Section 3. The costs associated with medical consumption are given as

$$tc_j = \varepsilon_j \left[\frac{\lambda_j m_{j,h}}{\exp(b_j)}\right], \tag{13}$$

where ε_j governs the severity of transaction friction. These costs have several properties. First, when the out-of-pocket medical spending λm increases, the cost tc also increases (i.e., $\partial tc/\partial \lambda m \geq 0$). Second, when individuals hold more bonds, the cost tc becomes

[5]The model does not reproduce the refund systems, including high-cost medical expense benefit system (*kogaku ryoyohi seido*) and medical deductions (*iryohi kojo*), for simplicity. Since they could make medical costs or tax burden faced by patients relatively light, it would be interesting to incorporate these medical systems into the model and investigate the effects of them.

smaller (i.e., $\partial tc/\partial b \leq 0$). This property is the most important and critical in the paper. Since holding liquid bonds can help reduce the transaction costs of medical spending, individuals facing health risk have a precautionary savings motive to hold liquid bonds rather than illiquid capital, despite the lower bond return. Particularly, in old age, individuals with higher medical expenditure risk have a stronger motive to hold liquid bonds. This mechanism generates the greater demand for liquid assets among the elderly and the positive premium between bond and capital returns. Third, when medical spending is zero, there is no transaction friction (i.e., $tc = 0$ if $m = 0$). Fourth, the marginal decline in costs from holding bonds diminishes as bond holdings increase (i.e., $\partial^2 tc/\partial (b)^2 \geq 0$). Finally, the marginal transaction cost of additional medical spending does not increase with bond holdings (i.e., $\partial^2 tc/(\partial \lambda m \partial b) \leq 0$).

It is worth emphasizing that this transaction friction includes psychological as well as monetary costs, although the formulation of the cost function is very similar to the shopping cost or time theory, as in Attanasio et al. (2002), Gavin et al. (2007, 2015), and Aoki et al. (2021). If individuals obtain poor health and suddenly need to pay a large amount of money in cash for medical care such as hospitalization, holding more liquid assets would be beneficial in terms of reducing in time and effort required to liquidate into money. In addition, the transaction costs partially capture the aspect that holding liquid bond to prepare for health risk events would reduce the individual's psychological anxiety or depression about their health and medical costs.

4.5 Production Technology

Firms are competitive and produce a homogenous good using capital stock and labor according to a constant returns to scale technology:

$$Y = K^{\alpha} (ZN)^{1-\alpha}, \tag{14}$$

where Y is aggregate output, K is aggregate capital, Z is labor-augmented TFP, N is aggregate effective labor, and α is capital's share of output. A homogenous good can be used as either consumption, medical consumption, or investment.

Firms maximize profits by setting the marginal productivity of labor equal to the wage rate:

$$w = MPL = (1-\alpha) Z^{1-\alpha} (K/N)^{\alpha}, \tag{15}$$

where MPL is the marginal productivity of capital, and the marginal productivity of capital is given by

$$MPK = \alpha Z^{1-\alpha} (K/N)^{\alpha-1}. \tag{16}$$

4.6 Government

The general budget of the government is balanced in every period. Revenues consist of newly issued bond D' and taxes on consumption, labor income, capital income, and bond income with the corresponding tax rates given by τ^c, τ^l, τ^k, and τ^b, respectively. Expenditures consist of an exogenous government expenditure G, an interest payment of the bond $\left(1+r^b\right) D$, pension benefits PB, medical benefits MB, and a government transfer TR, where r^b is the return on liquid bond b. Following Conesa et al. (2018) and Hsu and Yamada (2019), the government operates a pay-as-you-go public pension system, given by

$$PB = \sum_{s|j \geq j_r+1} pen_j \mu_j \Phi(s), \tag{17}$$

where

$$pen_j = \begin{cases} 0 & \text{if } j < j_r + 1 \\ \theta w N & \text{if } j \geq j_r + 1 \end{cases}, \tag{18}$$

where pen_j is pension benefits, μ_j denotes the population of age j, $\Phi(s)$ is a distribution function over individual state variables $s = \{j, x, \eta, \delta, h\}$, where j is age, x is cash on hand, η is an individual labor productivity, δ is an individual capital depreciation, and h is health status. The social security replacement rate is denoted by θ. Next, MB is the medical benefits that are covered by the government sector, given by

$$MB = \sum_s \{(1-\lambda_j) m_j\} \mu_j \Phi(s), \tag{19}$$

where $1-\lambda_j$ denotes the coverage rate. Finally, the government also provides a transfer benefit TR_t, given by

$$TR = \sum_s tr(s) \mu_j \Phi(s), \tag{20}$$

where tr is a means-tested transfer. I consider a simple transfer rule that guarantees each individual a minimum subsistence level of consumption $\underline{c}$, proposed by Hubbard et al. (1995). This safety-net program has a role to prevent individuals from suffering from small or possible negative consumption when confronting with out-of-pocket medical costs.

Put together, the government's budget constraint is given by

$$G+\left(1+r^{b}\right)D+PB+MB+TR=D^{'}+\sum_{s}\left(\tau^{c}c\left(s\right)\right)\mu_{j}\Phi\left(s\right)+$$

$$\sum_{s|j<j_{r}+1}\left(\tau^{l}w\eta_{j}e_{j}l\left(s\right)\right)\mu_{j}\Phi\left(s\right)+\sum_{s}\left(\tau^{k}r_{j}^{k}\left(k\left(s\right)+beq\right)\right)\mu_{j}\Phi\left(s\right)+\sum_{s}\left(\tau^{b}r^{b}b\left(s\right)\right)\mu_{j}\Phi\left(s\right), \tag{21}$$

where beq is a transfer of accidental bequests. I assume that all bequests by the deceased are left in the form of illiquid capital, including housing or land, and that these bequests are distributed to all survivors in a lump-sum fashion:[6]

$$beq=\frac{\sum_{s}\left(1-\psi_{j-1}\right)k\left(s\right)\mu_{j-1}\Phi\left(s\right)}{\sum_{j=1}^{j_{f}}\mu_{j}}. \tag{22}$$

4.7 Individuals Problem

Individuals choose consumption, capital holdings, and bond holdings, and pay for medical care and transaction costs, using capital and bond interest income, labor income, and pension benefits. Their budget constraint is defined as

$$\left(1+\tau^{c}\right)c+k^{'}+b^{'}=x+tr, \tag{23}$$

where

$$x=\left[1+\left(1-\tau^{k}\right)r_{j}^{k}\right]\left(k+beq\right)+\left[1+\left(1-\tau^{b}\right)r^{b}\right]b+\left(1-\tau^{l}\right)w\eta_{j}e_{j}l+pen-\lambda_{j}m-tc, \tag{24}$$

$$tc=\varepsilon_{j}\left[\frac{\lambda_{j}m}{\exp\left(b\right)}\right], \tag{25}$$

$$tr=\max\left\{0,\left(1+\tau^{c}\right)\underline{c}-x\right\}, \tag{26}$$

$$k^{'}\geq 0,\quad b^{'}\geq 0, \tag{27}$$

[6]There are no bequest motives in the model. Horioka (2021) suggests that, in Japan, the selfish life-cycle model with unintended or accidental bequests is more applicable rather than the dynasty or altruism model.

where x is cash on hand, which represents the individual's disposable income, excluding medical-related costs. Equation (25) shows the transaction friction of medical spending. As equation (26) shows, a transfer tr can be positive, if cash on hand is below the consumption floor $\underline{c}$. Because of the borrowing constraint (27), individuals are not allowed to borrow both capital and bond against future income.

For tractability, I here transform the budget constraint (23) in several aspects. First, I define total wealth a as the sum of liquid bond b and illiquid capital k: that is, $a = k + b$. In addition, I introduce a new variable κ, which represents the share of illiquid capital in total assets: that is, $k = \kappa a$. Individuals choose total asset holdings and the investment ratio of capital, instead of choosing capital and bond holdings. Second, after-taxed gross return is defined as R: that is, $R_j^k = 1 + \left(1 - \tau^k\right) r_j^k$ and $R^b = 1 + \left(1 - \tau^b\right) r^b$. Third, total labor income, including pension benefits, is defined as y: that is, $y = \left(1 - \tau^l\right) w\eta_j e_j l + pen$. Thus, individuals' budget constraints (23)-(27) can be rewritten as follows:[7]

$$x^{'} = \left[R^b + \kappa^{'} \left(R_{j+1}^k - R^b\right)\right] a^{'} + y^{'} + R_{j+1}^k beq - \lambda_{j+1} m^{'} - tc^{'}, \tag{28}$$

where

$$tc^{'} = \varepsilon_{j+1} \left[\frac{\lambda_{j+1} m^{'}}{\exp\left\{\left(1 - \kappa^{'}\right) a^{'}\right\}}\right], \tag{29}$$

$$a^{'} = x - \left(1 + \tau^c\right) c + tr, \tag{30}$$

$$tr = \max\left\{0, \left(1 + \tau^c\right) \underline{c} - x\right\}, \tag{31}$$

$$a^{'} \geq 0, \quad 0 \leq \kappa^{'} \leq 1. \tag{32}$$

The individuals problem can be formulated recursively. An individual chooses consumption c, labor supply l, savings $a^{'}$, and capital investment ratio $\kappa^{'}$ to maximize the expected discounted sum of utility in the rest of the life. The value function $V(s)$ of an individual in state $s = \{j, x, \eta, \delta, h\}$ is given as follows:

$$V(s) = \max_{c,l,a^{'},\kappa^{'}} \left[u(c,l) + \beta\psi_j \mathbb{E}\left\{V\left(s^{'}\right)\right\}\right], \tag{33}$$

[7]As seen in equation (28), consumption tax is not imposed on medical consumption. In the actual economy, the costs of treatment and drugs covered by public health insurance are tax-free.

subject to equations (28)-(32), where $s' = \left\{j+1, x', \eta' = \eta_{j+1}, \delta' = \delta_{j+1}, h' = h_{j+1}\right\}$ is the state in the next period.

4.8 Competitive Equilibrium

A competitive equilibrium for this economy consists of a sequence of individuals' decision rules $\{c(s), l(s), x(s)\}$, firms' decision rules $\{K, N\}$, factor prices $\left\{r_j^k, w\right\}$, bond return r^b, government tax systems $\left\{\tau^c, \tau^l, \tau^k, \tau^b\right\}$, government expenditure G, pension systems θ, medical systems λ_j, means-tested transfers $tr(s)$, accidental bequests beq, and a population distribution $\Phi(s)$ such that:

1. Individuals solve the optimization problems described in Section 4.7.
2. Firms maximize their profits and factor prices are determined competitively.
3. Budget constraint for the government sector is satisfied.
4. The labor, capital, bond markets clear:

$$N = \sum_{s|j<j_r+1} \left(\eta_j e_j l(s)\right) \mu_j \Phi(s), \tag{34}$$

$$K = \sum_{s} \left(k(s) + beq\right) \mu_j \Phi(s), \tag{35}$$

$$D = \sum_{s} b(s) \mu_j \Phi(s). \tag{36}$$

5. The goods market clears:

$$Y - TC = C + \delta K + G + M, \tag{37}$$

where TC is aggregate transaction cost and C is aggregate consumption, given by

$$TC = \sum_{s} tc(s) \mu_j \Phi(s), \tag{38}$$

$$C = \sum_{s} c(s) \mu_j \Phi(s). \tag{39}$$

Table 1: Parameters Set Outside the Model

Parameter	Description	Source	Value
Preference			
γ	risk aversion	Hsu and Yamada (2019)	3.0
Labor productivity process			
ρ_η	persistence parameter	Hsu and Yamada (2019)	0.98
σ_η	standard deviation	Hsu and Yamada (2019)	0.09
Production technology			
Z	TFP parameter	normalized	1.0
α	capital share	Imrohoroglu and Sudo (2011)	0.377
$\overline{\delta}$	average capital depreciation	Sudo and Takizuka (2020)	0.06
Capital depreciation process			
ρ_δ	persistence parameter	Aladangady et al. (2021)	0.90
σ_δ	standard deviation	Unconditional Std. dev.=3.58%	0.0156
Government			
D	government bond supply	Net liquid assets	119.0% of GDP
r^b	return on liquid bond	Real return on liquid assets	0.5%
τ^c	consumption tax	in 2014	8.0%
τ^k	tax on illiquid capital	Imrohoroglu and Sudo (2011)	39.8%
τ^b	tax on liquid bond	Kitao (2015)	20.0%
τ^l	labor income tax	Kitao (2015)	35.0%
λ_j	copayment rate	MHLW (2010)	{30.0%, 20.0%, 10.0%}
$\underline{c}/\overline{C}$	fraction of consumption floor	Hsu and Yamada (2019)	10.0%

Table 2: Parameters Calibrated Specific to the Model

Parameter	Description	Target	Value
Preference			
β	subjective discount factor	$K/Y = 3.52$ (Gross illiquid assets)	1.011
σ	weight on consumption	average work time = 40%	0.38
ε_j	severity of transaction friction	(i) Ratio of liquid to illiquid in age 30-39 (ii) Ratio of liquid to illiquid in age 50-59 (iii) Bond market is cleared	7.5 if $1 \leq j \leq 19$ 14.1 if $20 \leq j \leq 39$ 12.0 if $40 \leq j \leq 80$
Government			
G/Y	government spending of GDP	Government budget is satisfied	16.7%
θ	replacement ratio	$PB/Y = 10.0\%$	50%

5 Calibration

This section describes the calibration of parameters. The model parameters consist of two groups. Parameters in the first group are standard in the literature, and their values are summarized in Table 1. Parameters in the second group are specific to this model. Specifically, I calibrate the model to the Japanese economy of 2014 by assuming that the economy is in a steady state. The calibrated parameters are summarized in Table 2.

5.1 Demographics

In the initial steady state, the population distribution is set to the actual data in 2014, where the data are taken from the National Institute of Population and Social Security Research (IPSS).[8] The growth rate of new cohorts n is set at the IPSS projection up to 2050, and the rate is assumed to increase linearly to zero by 2065 and remain constant after 2065. The survival rates ψ_j are set to the IPSS estimate up to 2060, and they are assumed to be constant after 2060.

5.2 Health Shock and Medical Spending

As mentioned by Hsu and Yamada (2019), micro-level panel data on health and medical expenditure are not publicly accessible in Japan. To obtain the medical expenditure profiles, this paper uses Fukai et al. (2018), who estimate the health expenditure level by age using data from the Claims Database of Japan Medical Data Center (JMDC). They provide the rich micro-based results regarding health distribution and age- and health-dependent medical expenditure. In my model, an individual health status is binary, "good" ($h = g$) or "bad" ($h = b$).[9] The classification of health group is based on the amount of medical expenditure, according to Fukai et al. (2018).[10] The health

[8]Since I use the actual population in 2014, the population in the initial steady state is not stationary. I assume that individuals solve the optimization problem given the survival probabilities of 2014, and aggregate variables are calculated using the actual age-distribution of 2014.

[9]Two health groups may not be sufficient to capture the highly skewed cross-sectional distribution of medical expenditures in the real economy. However, it would be difficult to introduce more health groups, because I use the estimation results from Fukai et al. (2018). Nonetheless, as shown in Figure 7, there is a significantly large difference in medical expenditures between the two health groups in the model. This implies that the model can partially capture the large uncertainty in medical expenditures.

[10]According to this classification, the healthy group would include low-income individuals who, despite their poor health, have few medical expenses. More precisely, health shocks should be considered as medical expenditure shocks in the model.

transition probabilities in my model are set by using the population distribution of health conditions by age group reported by their paper. The calibrated health transition probabilities and health distribution are shown in Figure 6. The probability of transitioning from "good" to "bad" is monotonically increasing with age, whereas that from "bad" to "good" declines with age.

Figure 6: Transition of Health (Left Panel) and Health Distribution (Right Panel)

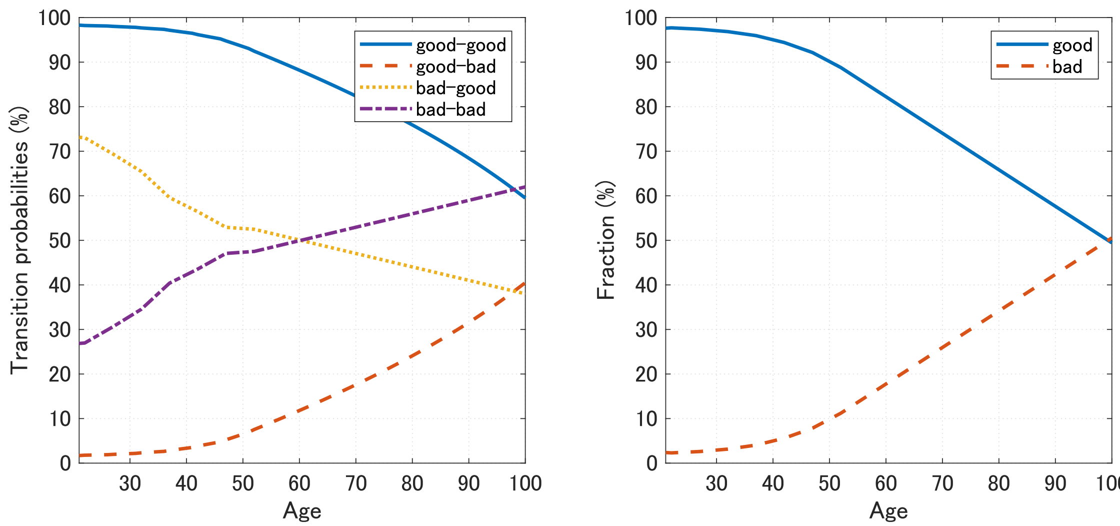
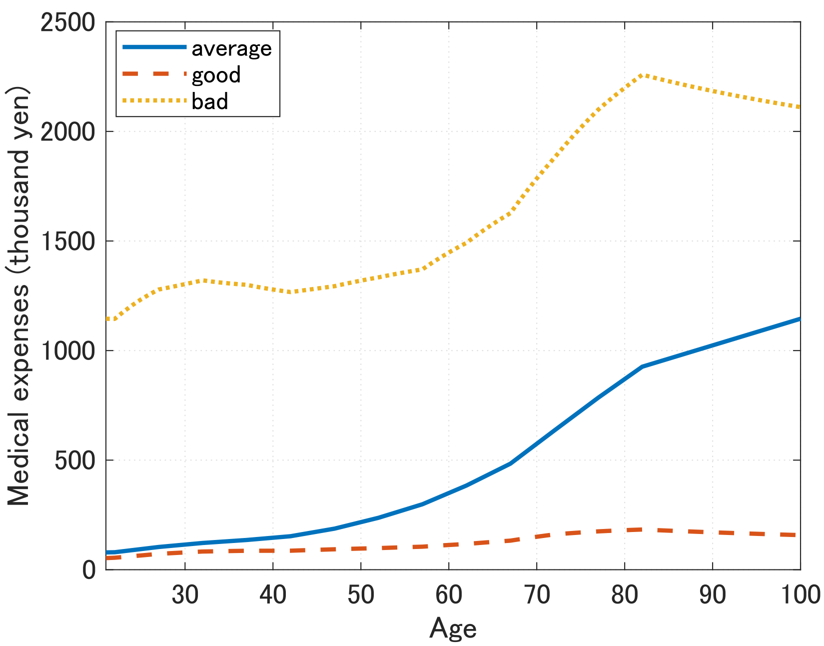


Figure 7: Medical Expenditure by Age and Health



Fukai et al. (2018) also report the distribution of annual medical expenditure by age group. Using these data, the life-cycle profiles of medical expenditure for "good" and "bad" health conditions are calibrated, as shown in Figure 7.[11]

5.3 Preference

I classify total assets into two groups: liquid and illiquid. I define liquid assets as the sum of cash, deposits, and bond, and illiquid assets as the sum of stocks, private life insurance and pensions, and capital (including housing and other real estate). The subjective discount factor β is chosen so that $K/Y = 3.52$, which is the gross illiquid assets of GDP in 2014. The weight on consumption σ is set so that individuals spend approximately 40% of their disposable time on work. The risk aversion parameter γ is set to 3 as in Hsu and Yamada (2019). In my baseline model, based on the weight on consumption σ of 0.38, we obtain the risk aversion over consumption $(\gamma - 1)\sigma + 1$ of 1.76. This value is consistent with many macroeconomic literatures.

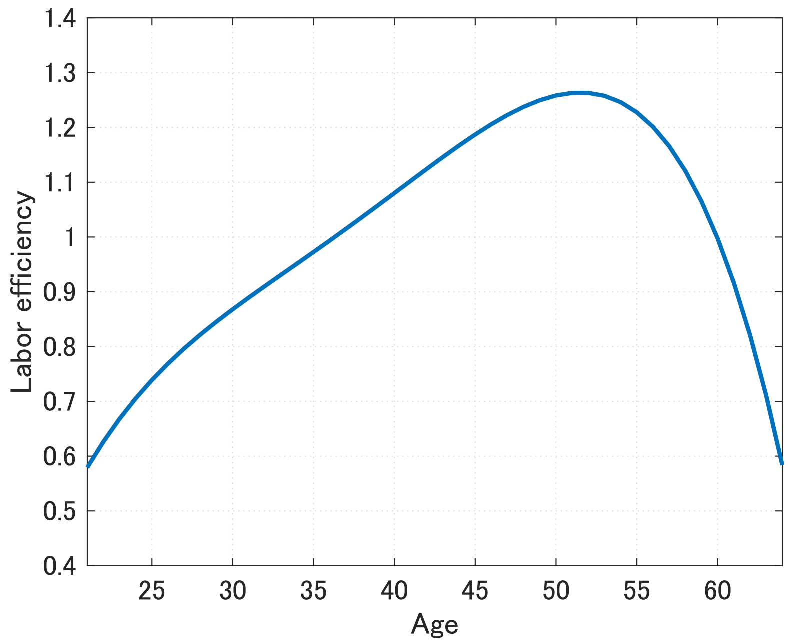
In the model, the transaction friction parameter ε_j is the key parameter to generate the demand for liquid bonds with lower return. I assume that the parameter depends on age and takes three different values in young, middle, and old age groups. Each group corresponds to age 21-39, age 40-59, and age 60-100, respectively. This age-dependent transaction parameter can well capture the household asset portfolio by age in the real economy. I calibrate the three different values of ε_j so that (i) the model-generated individual's asset portfolio matches the ratio of liquid assets to illiquid assets of age groups 30-39, (ii) it also matches the ratio of liquid assets to illiquid assets of age groups 50-59, and (iii) the aggregate bond market is cleared ($\sum_s b(s)\mu_j \Phi(s) = D$), given the bond return r^b and the supply of government bonds D as mentioned in Section 5.6.

5.4 Endowments and Labor Productivity Shock

The individual labor efficiency e_j is set using data from the Basic Survey on Wage Structure (BSWS) by the Ministry of Health, Labour and Welfare (MHLW). The estimated wage profile is shown in Figure 8. The individual labor productivity shock η is approximated by an AR (1) process with a three-state Markov chain using the method

[11]For more details about the computation of age- and health-dependent medical expenditure, see Appendix A.

Figure 8: Labor Efficiency Profile



of Tauchen (1986):

$$\log(\eta_{j+1}) = \rho_\eta \log(\eta_j) + \pi_{\eta,j}, \tag{40}$$

where $\pi_{\eta,j} \sim N\left(0, \sigma_\eta^2\right)$. Following Hsu and Yamada (2019), persistence parameter ρ_η is set at 0.98, and standard deviation of the shock σ_π is set at 0.09.

5.5 Technology and Capital Depreciation Shock

The labor-augmented TFP Z is normalized to 1. The capital share α is set to 0.377, based on Imrohoroglu and Sudo (2011). The depreciation of capital has two parts: deterministic and stochastic. First, the deterministic part, denoted by $\overline{\delta}$, represents the average depreciation and I set the value at 0.06, following Sudo and Takizuka (2020). Second, the stochastic part partially contributes to the liquid bond demand because of the riskiness of illiquid capital. The depreciation shock δ is approximated by an AR (1) process with a two-state Markov chain:

$$\log(\delta_{j+1}) = \rho_\delta \log(\delta_j) + \pi_{\delta,j}, \tag{41}$$

where $\pi_{\delta,j} \sim N\left(0, \sigma_\delta^2\right)$. Following Aladangady et al. (2021), persistence parameter ρ_δ is set at 0.90. Regarding the standard deviation of the shock σ_δ, I set the value of 0.0156, such that the unconditional standard deviation of the autoregressive process is 3.58%.

5.6 Government

I set the supply of government bonds $D/Y = 1.19$, which is the net liquid assets of GDP in 2014. I assume that the ratio is constant over time.[12] The return on bond is set at 0.5%. This is the average value of the real interest rate of 10-year bonds during 2010-2014, which is calculated by the long-term nominal interest rate minus the CPI inflation rate. The consumption tax rate τ^c is set at 8% in 2014. The capital income tax rate τ^k is set at 39.8% following Imrohoroglu and Sudo (2011), and the bond income tax rate τ^b is set at 20.0% according to Kitao (2015). The labor income tax rate τ^l is set at 35.0% according to Kitao (2015), which includes insurance premiums for public pensions and public health care in the real economy. These tax rates are assumed to be constant. The government spending of GDP G/Y is set so that the government budget (21) holds. The replacement rate θ is set to 50.0% and the implied total pension benefits are 10.0% of GDP, close to the real value in 2014. All residents benefit from universal health care provided by the government. The copayment rate λ_j currently depends on age: 30% under age 70, 20% between age 70 and 74, and 10% at age 75 and over.[13] I set the consumption floor $\underline{c}$ at 10% of average consumption $\overline{C}$, following Hsu and Yamada (2019).

5.7 Model Fits

Table 3 provides the aggregate moments in the steady state of my model. The model reproduces some of main features of the Japanese economy, including returns on bond and capital, aggregate liquid bond, aggregate illiquid capital, and the composition of aggregate output.

[12] The assumption of a fixed bond supply would be a strong and unrealistic, since the public debt has increased significantly over these several decades. However, it allows for us to clearly understand the impact of demographic aging and changes in healthcare systems, as noted in Kopecky and Taylor (2022). In the section 6.4, I relax the assumption and analyze the impact of changes in the supply of the government bonds.

[13] In the actual economy, the copayment rate is still 30% for those who are over age 70 but have as much income as active workers. However, they represent only 7% of the population, and I therefore omit them.

Table 3: Aggregate Moments: Model vs Data

Parameter	Description	Steady-state value	Data
r^k	Average return on capital	4.67%	5.39%
r^b	Return on bond	0.50%	0.44%
$r^k - r^b$	Average risk premium	4.17%	4.95%
$R^k - 1$	Post-tax return on capital	2.81%	3.24%
$R^b - 1$	Post-tax return on bond	0.40%	0.35%
$R^k - R^b$	Post-tax premium	2.41%	2.89%
D/Y	Debt-output ratio	1.19	1.19
K/Y	Capital-output ratio	3.53	3.52
G/Y	Government expenditures of output	0.17	0.13
PB/Y	Pension benefits of output	0.10	0.10
M/Y	Medical expenditures of output	0.07	0.08
MB/Y	Medical benefits of output	0.06	0.07
$(M - MB)/Y$	Out-of-pocket medical costs of output	0.01	0.01
TC/Y	Transaction costs of output	0.07	–

Figure 9: Assets, Consumption, and Work Hours over the Life-Cycle

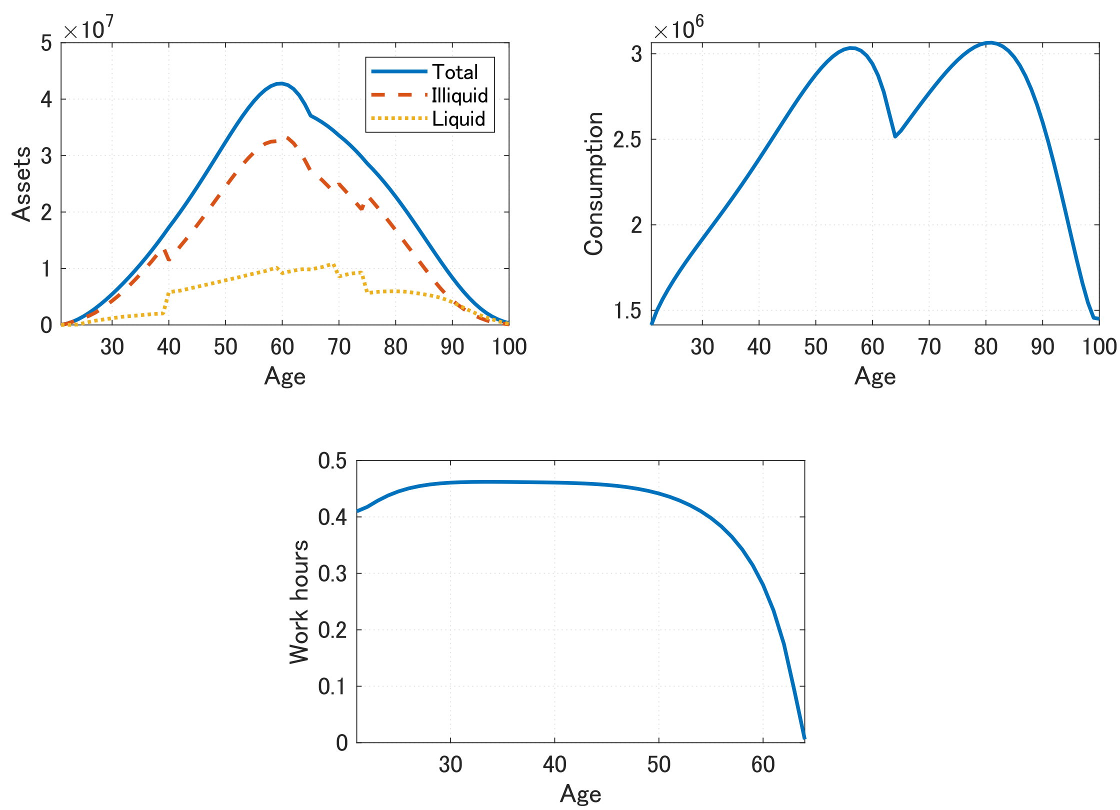


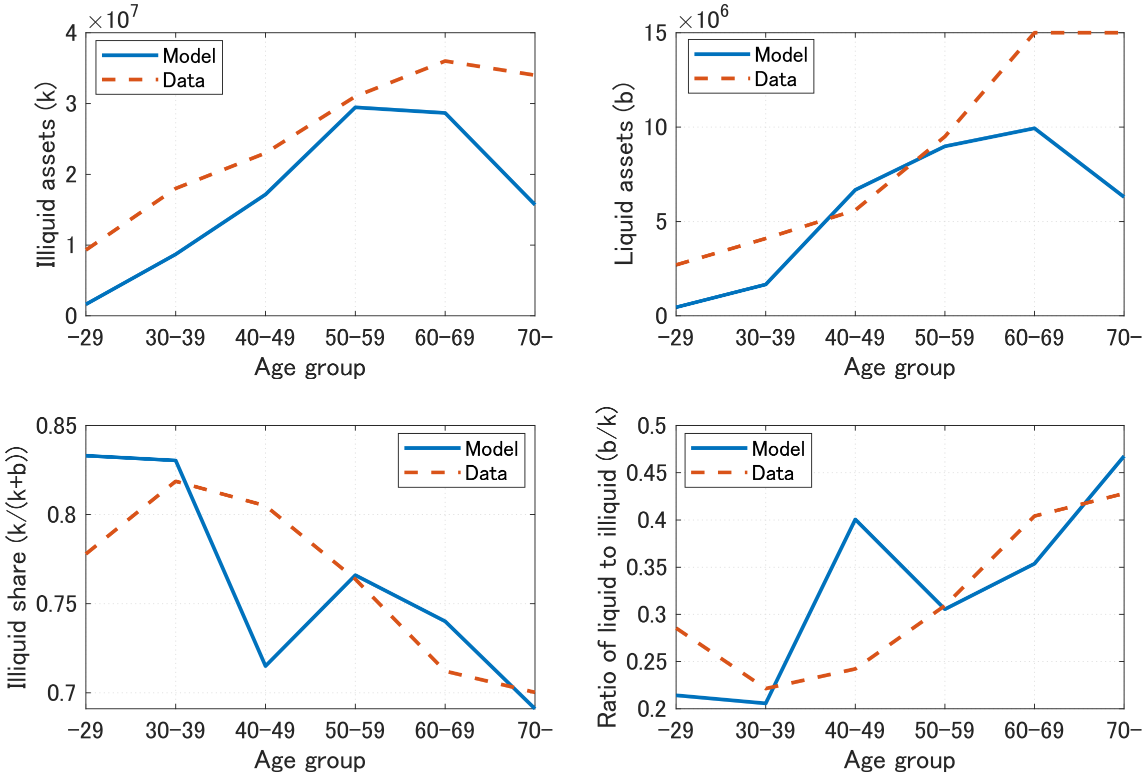
Figure 9 shows life-cycle profiles of assets, consumption, and work hours in the model. First, individuals accumulate wealth after entering the economy, and start to dissave as they approach retirement age. Next, consumption rises sharply during the working period and declines thereafter, exhibiting a mild hump-shaped profile. Finally, work hours are relatively flat until around age 50, but then decline sharply in the 50s and 60s. These life-cycle patterns are consistent with data from Kitao (2015) and Imrohoroglu et al. (2016).

Next, Figure 10 represents liquid and illiquid assets over the life-cycle in the model and data. In order to compare the wealth level and the ratio of different types of assets in the model with those in the data, I can compute the average values within six age groups (under 29, 30-39, 40-49, 50-59, 60-69, and over 70). First, the level of illiquid assets in the model is a little lower than that in the real economy. However, the model captures the shape of the risky asset holdings over the life-cycle relatively well. Second, the level of liquid assets is also lower than that in the data. In particular, those aged over 70 in the model have much lower liquid asset holdings than household in the real eocnomy. The feature is also seen in the illiquid asset holdings. This is mainly because of the assumption that the level of wealth becomes finally zero at age 100 and the absence of the bequest motive in the model. Third, however, the model successfully generates the relative ratio between liquid assets and illiquid assets in the data. Since both levels of liquid and illiquid assets decline within the elderly group in the model, the relative size of the two assets matches the data well. In addition, in order to reproduce the household asset portfolio by age in the real economy, it is important to assume that the transaction severity parameter ε_j increases with age, as mentioned in Section 5.3.[14]

Finally, Figure 11 shows the average transaction cost over the life-cycle. There are three reasons why transaction costs increase with age. First, the probability of getting poor health is higher in old age, as shown in Figure 6. Second, the elderly have higher medical expenses on average, as shown in Figure 7. Third, as mentioned above, I assume that the transaction frictions are more severe in old age, such that I can reproduce the life-cycle asset portfolio of households in the real economy. For example, from the left panel, the amount of transaction friction at age 60 can be 400 thousand yen. In addition, from the right panel, the average transaction friction in

[14]If I assume the same transaction parameter ε for all age groups, the model does not capture the lower ratio of liquid to illiquid asset in the younger age group. This is because the large transaction costs encourage even younger individuals, such as those aged -29 and 30-39, who have a low probability of getting poor health and are likely to incur small medical expenditure, to save more in the form of liquid assets.

Figure 10: Liquid and Illiquid Asset Holdings by Age Group: Model vs Data

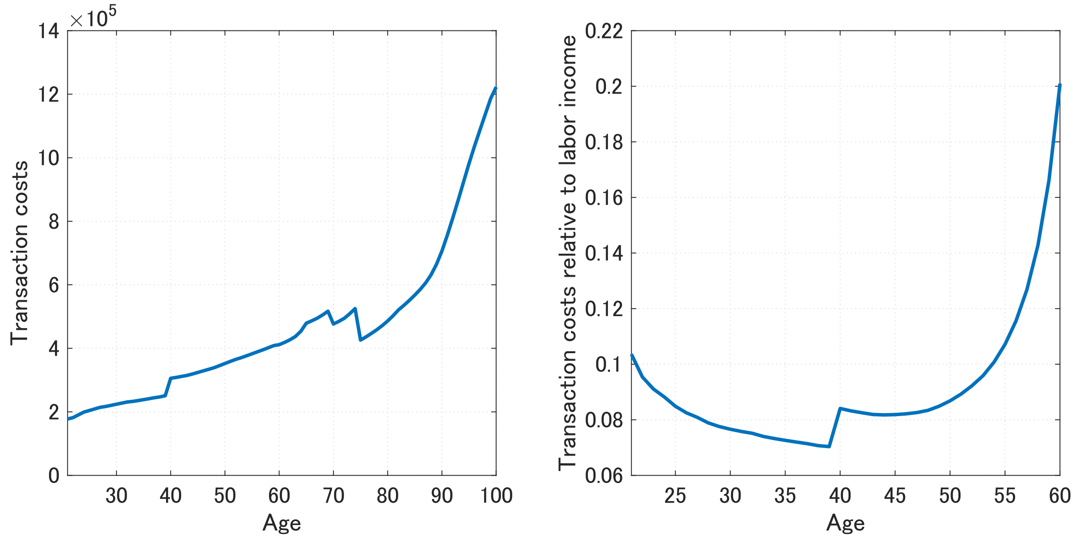


the working age period is about 10% of their labor income. These costs seem large compared to out-of-pocket medical costs or consumption. Nonetheless, note that they include potential costs associated with medical care, not only pecuniary costs but also psychological costs.

6 Steady State Results

The focus of this section is to analyze the impact of population aging and presence of health risk and medical expenditures on macroeconomic variables, including aggregate output, aggregate liquid bond, aggregate illiquid capital, and returns on two types of assets and their gap (i.e., risk premium). Specifically, I first compute the steady-state equilibrium in the benchmark year 2014. Then, I simulate the model under real structures in terms of population and healthcare systems in the years 1990 and 2000. Here I assume that these also represent a steady state where the demographic and

Figure 11: Transaction Costs over the Life-Cycle



medical structures are stable.[15]

Demographics in Japan have significantly changed over past several decades. Due to the lower fertility and longer life expectancy, Japan has experienced a sharp rise in the ratio of the old retired population to the young working-age population. Table 4 shows aging rate and dependency ratio in three years: 1990, 2000, and 2014. According to data from the IPSS, the aging rate was only 16.8% in 1990. However, it has increased to 22.1% in 2010 and 31.9% in 2014. In addition, the dependency ratio has increased 46.7% in 2014 from 20.2% in 1990.

Moreover, medical structures have changed significantly over the past thirty years. Table 5 shows health care systems in three years. First, per capita medical expenditure has increased due to medical technological progress and an increase in household income. According to data from the MHLW, in 1990, while the average per capita expenditure was 70 thousand yen for those of aged 21 to 44, it was 594 thousand yen for those of over age 65. However, in 2014, the former expenditure has increased to 121 thousand yen and the latter expenditure has increased to 861 thousand yen.

Second, apart from the total medical expenditure, the government has raised the copayment rate for public health insurance. In 2014 and now, the copayment rates differ by age and are 30.0% for those aged 21-69, 20.0% for those aged 70-74, and 10.0% for those aged 75 and over. Similarly, in 1990 and 2000, copayment rates were lower for the elderly, but the out-of-pocket rates were trivial compared to 2014, not

[15]For details of the numerical procedures, see Appendix B.

Table 4: Structural Change for Demographics

	1990	2000	Bench (2014)
Aging rate	16.8%	22.1%	31.9%
Dependency ratio	20.2%	28.3%	46.7%

Notes: Aging rate is the ratio of the population of aged 65 and over to the population aged 21-100, and the dependency ratio is the ratio of the population aged 65 and over to the population aged 21-64.

Table 5: Structural Change for Medical Systems

	1990	2000	Bench (2014)
Per capita medical expenditure (thousand yen)			
21-44	70	105	121
45-64	180	248	279
65+ (75+)	594 (673)	772 (860)	861 (976)
Copayment rates			
21-69	10.0%	20.0%	30.0%
70-74	19200 yen (400 yen per day)	10.0%	20.0%
75+	19200 yen (400 yen per day)	10.0%	10.0%

only for the elderly but also for the younger, compared to 2014. In 1990, the individual burden of the elderly for outpatient medical care was only 400 yen per day, while that for impatient medical care was only 300 yen per day. Accordingly, in the model, I assume that individuals visit medical institutions four times a month and their average annual payment for medical care is 19200 yen (400 yen*4 times*12 months). On the other hand, the copayment rate for younger people was 10.0% for the employee's health insurance. In 2000, the copayment rates were higher than those in 1990, but the rates were 10.0% for the elderly over 70 and 20.0% for those under 69 with the employee's health insurance.

In the model, all demographic and medical structural changes could increase the demand for liquid assets, reduce the return on bond, and widen the gap between liquid and illiquid assets. Individuals have a precautionary savings motive to prepare for out-of-pocket medical expenses and value liquid assets more due to the existence of the transaction frictions. Population aging leads to a relative increase in the number of elderly people with higher health riska and larger medical expenditures. In addition, the higher individual medical burden caused by the change in medical structures increases the advantage of holding liquid assets through the transaction cost mechanism. Therefore, these would result in an increase in the aggregate demand for liquid assets

Table 6: Model Equilibrium Macroeconomic Variables

	Bench (2014)	1990	2000
Capital K	2.20	1.87	1.99
Labor supply N	0.29	0.32	0.31
Work hours l	0.41	0.36	0.38
Output Y	0.62	0.62	0.63
Consumption C	0.31	0.31	0.31
Bond $D\,(= 1.19 * Y)$	0.74	0.74	0.75
Medical spending of output M/Y	7.0%	3.4%	5.2%
Wage w	1.34	1.21	1.25
Average return on capital r^k	4.7%	6.6%	5.9%
Return on bond r^b	0.5%	3.8%	2.6%

and reduce the equilibrium interest rate, such that the bond market is cleared. This expected relationship is based on the two-period analytical results, discussed in Figure 5 in Section 3.

6.1 Model Aggregate Outcomes

In Table 6, I show the aggregate values in three steady states: 1990, 2000, and 2014 (benchmark year). I focus on the bench year 2014 and discuss the changes in the aggregate outcomes from years 1990 and 2000. First, the aggregate capital stock has increased. This is mainly because the decline in survival rates and the increase in out-of-pocket medical expenditures have encouraged individuals to save more illiquid assets for longer their lives in old age. In addition, the aging of the population has changed the demographic structure, leading to a larger older population with higher asset holdings. These have led to an increase in the aggregate stock of capital.

Second, while the aggregate labor supply has declined, hours worked have increased. Longer longevity has also promote individuals to work more. However, the over all impact of demographic and medical structural changes on aggregate labor is negative because of the large decline in the size of the younger population.

Third, output has not changed much because the positive effects of the increase in the capital are offset by the negative effects of the decrease in the labor. the aggregate bond demand is stable under the assumption of the constant debt-to-output ratio. On the other hand, medical expenditures have risen sharply in line with medical structural changes.

Finally, both the return on capital and the return on bond have dropped. However, the decline in the bond return is much larger than that of the capital return: from 1990 to 2014, the former is -3.3% and the latter is -1.9%. Thus, the difference between the two returns (premium) has increased from 2.8% to 4.2%.

In the following, I first compare the premium changes in the model and the data to check whether the model reproduces the widening gap between two asset returns. Next, I decompose the premium changes in the model into the contributions of the demographic factor and the medical factor. This allows us to identify the major contributors to premium changes over several decades in Japan.

6.2 Returns and Risk Premium

Table 7 summarizes the changes in the risk premium and the two asset returns in the model and the data. Here I calculate the post-tax returns $R^k - 1$ and $R^b - 1$, and the premium $R^k - R^k$. As observed from the table, the model can capture well the changes in returns and the gap in the data, except for the return on capital. In the model, the capital return declines because of the rise in the capital-labor ratio due to population aging. On the other hand, in the real economy, the capital return has remained relatively stable or increased slightly. This is a large gap between the model and the data. Nonetheless, the model reproduces the large decline in the bond return. The main mechanism behind the decline is the transaction friction associated with medical spending. I discuss this point in the next section. Overall, the model generates the positive and relatively large change in post-tax premiums of 1.5% from 1990 to 2014, which is more than half of the data value of 2.7%.

6.3 Decomposition of Premium Changes

Now, to further investigate why the bond return declines more than the capital return, I decompose the premium changes into several components. The first is the effect related to the changes in the demographic structure, such as the rise in the ratio of the old retired population to the young working-age population. The second is the effect of the increase in per capita medical expenditure, and the third is the effect of the rise in copayment rates. The second and third effects are related to the changes in the medical

Table 7: Two Asset Returns and the Gap

	1990	2000	Bench (2014)	Change direction
Model				
Post-tax premium $R^k - R^b$	0.9%	1.5%	2.4%	$\Uparrow$
Post-tax return on capital $R^k - 1$	4.0%	3.6%	2.8%	$\Downarrow$
Post-tax return on bond $R^b - 1$	3.0%	2.1%	0.4%	$\Downarrow\Downarrow$
Data				
Post-tax premium $R^k - R^b$	0.2%	1.4%	2.9%	$\Uparrow$
Post-tax return on capital $R^k - 1$	3.0%	3.2%	3.2%	$\Rightarrow$
Post-tax return on bond $R^b - 1$	2.8%	1.8%	0.4%	$\Downarrow\Downarrow$

Table 8: Decomposition: Premium Changes

	Risk premium $R^k - R^b$	Capital return $R^k - 1$	Bond return $R^b - 1$
Total changes (from 2000 to 2014)	+0.9%	−0.7%	−1.7%
(i) Demographics	+0.2%	−0.8%	−1.0%
(ii) Medical expenditures	+0.2%	+0.01%	−0.2%
(iii) Copayment rates	+0.5%	+0.04%	−0.5%
Total changes (from 1990 to 2014)	+1.5%	−1.2%	−2.6%
(i) Demographics	+0.3%	−1.3%	−1.6%
(ii) Medical expenditures	+0.6%	+0.1%	−0.6%
(iii) Copayment rates	+0.6%	+0.1%	−0.5%

structure.

Table 8 presents the results of this decomposition. The second and sixth rows show the total changes in the two asset returns and the gap, respectively. From the third to the fifth row and from the seventh to the ninth row, the contributions of each structural changes are shown. For example, the demographic contribution (i) is calculated by simulating the model in 1990 and 2000 with only the demographic change, keeping the other medical structures in 2014. Medical contributions (ii) and (iii) are also calculated in the same way.

First, the demographic change (i) has pushed down both returns on capital and bond. Changes in the population distribution toward more older people, due to aging, could increase both aggregate capital demand and aggregate bond demand, because the older people are likely to have more liquid and illiquid assets. The increase in the capital reduces the marginal productivity of capital and the return on illiquid capital. On the other hand, given a constant aggregate bond supply, the increase in the bond demand allows the equilibrium return on liquid bond to fall. Since the demographic change has the larger negative impact on the bond return, it has increased the risk premium. However, the contribution is 0.2% from 2000 to 2014 (0.3% from 1990 to 2014), which is very small compared to the total change of 0.9% from 2000 to 2014 (1.5% from 1990 to 2014). Second, medical changes, including (ii) and (iii), have pushed down the return on bond, while they have not affected the return on capital. These differences are brought by the transaction cost mechanism in the model. The increases in medical expenditure or the copayment rate lead to the rise in out-of-pocket medical expenditure. Such an increase in medical expenditure risk promotes individuals to have a stronger motive for precautionary saving in the form of liquid assets to mitigate the associated medical transaction costs. As a result, aggregate demand for bond has increased significantly, leading to a further decline in the equilibrium rate of return on bond. To same extent, premium changes over several decades can be explained by this additional downward pressure on the bond rate through transaction frictions.

6.4 Future Projection

Finally, this section discusses the future projection for two asset returns and risk premium. Specifically, I simulate the model in 2030 and 2060 under (i) the projected further aging, (ii) the projected increase in medical expenditures, (iii) the reform of raising copayments, and (iv) the relaxed assumption of a constant debt-to-GDP ratio. Table 9 summarizes the model's assumption about the future economic conditions in three years: 2014 (benchmark year), 2030, and 2060.

First, population aging is expected to worsen in the future. According to the IPSS population projection data, the aging rate will increase from 31.9% in 2014 to 37.2% in 2030 and 44.6% in 2060. Second, I assume that per capita medical expenditure will increase in the future at the same rate of change from 2000 to 2014. The growth rates are 15.2% for those aged 21-44, 12.5% for those aged 45-64, and 11.5% for those aged over 65, respectively. Third, I assume that the government will increase the copayment rates for those over 75 from the current 10.0% to 20.0%. Finally, I relax the assumption of a constant debt-to-output ratio in the above analyses and allow that Japan will experience a significant increase in government debt. In the benchmark year 2014, the net liquid assets of GDP D/Y is set at 1.19, as mentioned in Section 5.6. In fact, the ratio in the real economy has been relatively low over the past twenty years: 0.82 in 1994 and 0.95 in 2000. Therefore, I assume that the net liquid assets of GDP will increase in the future at the same rate of change from 2000 to 2014. Since the

Table 9: Assumption about Future Economic Structures

	Bench (2014)	2030	2060
Population aging			
Aging rate	31.9%	37.2%	44.6%
Dependency ratio	46.7%	59.1%	80.5%
Per capita medical expenditure (thousand yen)			
21-44	121	139	185
45-64	279	314	397
65+	861	960	1194
Copayment rates			
75+	10.0%	20.0%	20.0%
Government bond supply			
Debt-to-GDP ratio	119.0%	144.0%	194.0%

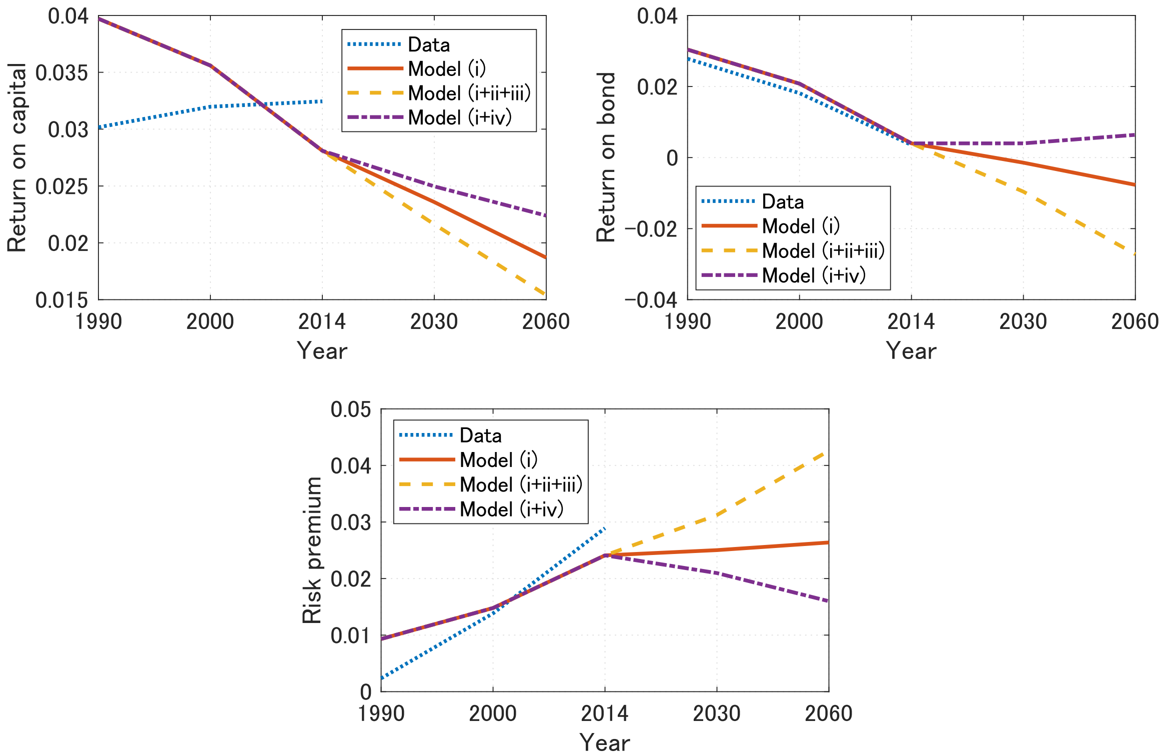
Notes: Aging rate is the ratio of the population of aged 65 and over to the population aged 21-100, and the dependency ratio is the ratio of the population aged 65 and over to the population aged 21-64.

increase in the government bond supply would place upward pressure on the bond rate, the potentially positive premium changes could be mitigated.

In Figure 12, I show the past and future projected changes in the capital return, bond return, and risk premium in the model and the data. In the model with only demographic change (i), both returns on capital and bond will decline after 2014. Although the premium will increase because of further decline in the bond rate, the increase is trivial: 2.50% in 2030 and 2.64% in 2060, compared to 2.41% in 2014. On the other hand, in the model that includes not only demographic change (i) but also medical structural change (ii) and the health insurance reform (iii), returns on capital and bond will decline much and the premium is expected to become larger: 3.12% in 2030 and 4.26% in 2060, compared to 2.41% in 2014. This is because the changes in the healthcare system contribute significantly to the changes in the premium through the transaction costs of medical spending in the model.

Finally, the model (i+iv) shows the results of the model simulation with demographic change (i) and the increase in bond supply (iv). If I allow for the future increase in the bond supply, the premium tends to decrease: 2.10% in 2030 and 1.60% in 2060, compared to 2.41% in 2014. This is because, as shown in the upper right panel in Figure 12, the bond return will increase in the opposite direction from 2014. The upward pressure on the bond rate from an increase in the bond supply would be very large. Nonetheless, whether or not the premium will continue to rise in the future depends strongly on the magnitude of the effects of (i)-(iv). If the negative impact caused by the changes in the bond supply is dominated by the positive impacts caused by the changes in demographics and medical systems, the premium will still rise.

Figure 12: Future Projection of Return on Capital, Return on Bond, and the Risk Premium



Notes: Model (x) (x=i, i+ii+iii, and i+iv) represents the model simulation results with future assumption x, respectively.

7 Conclusion

In Japan, the return on liquid assets, including cash, deposits, and bond, has declined over several decades. In contrast, the return on illiquid assets, including equity and capital, has remained stable, thus the gap between two asset returns (i.e., risk premium) has widened. This paper focuses on health or medical expenditure risk as a potentially important factor behind household saving behavior, and quantifies the impact of demographic and medical structural changes on the return on the liquid bond and the premium.

I start with a two-period, partial equilibrium, model and present the analytical results. The feature of the model is to introduce the transaction cost mechanism associated with medical spending, leading to a positive demand for liquid bond which has a lower return than illiquid capital. Individuals in the model face health risk and they need to consume medical goods if they get poor health in old age. In addition, I assume that they incur transaction costs of medical spending, including pecuniary and non-pecuniary (e.g., psychological) costs. These costs increase with medical expenditure, but can be mitigated by holding liquid assets. Thus, individuals hold more liquid bond to prepare for the health and medical risks and to reduce the additional medical transaction costs. If these risks rise, the bond demand will increase and the equilibrium bond return will drop.

To investigate quantitatively the role of health and medical expenditure risk on the bond return and the premium, I next develop a dynamic stochastic general equilibrium overlapping generations model with heterogeneous individuals who are different in their age, labor productivity, capital depreciation, wealth, and health status. I have two main quantitative results. First, the expansion of the risk premium over this several decades has been mainly driven by structural changes in the medical system, such as the increase in per-capita medical expenses and the rise in the copayment rates, rather than by demographic aging. Demographic aging has brought about the increase in both aggregate liquid bond and illiquid capital because older households hold more assets. The increase in the aggregate capital stock and the decrease in the aggregate labor supply lead to a rise in the capital-labor ratio, reducing the capital return. On the other hand, the increase in the aggregate bond demand pushes down the bond return such that bond market is cleared. Because of this decline in both returns, demographic factors could not change the premium much. In contrast, the increase in out-of-pocket copayments due to medical structural changes reduce only bond return. This is mainly because liquid bond holdings has an advantage of mitigating medical transaction costs. Individuals, especially the elderly who are exposed to higher health and medical expenditure risk, have stronger motive for precautionary saving in the form of liquid assets. It leads to a significant increase in the aggregate bond demand, placing further downward pressure on the bond return and upward pressure on the premium.

Second, whether the increasing trend of the gap will continue in the future depends on several future economic conditions: demographics, medical systems, and government bond supply. The future projection of demographic aging alone will contribute to the increase in the premium, but the change would be trivial. If I take into account the continued substantial rise in government debt, the future direction of the premium could be the opposite, a decline. Nonetheless, the upward pressure on the premium could be strengthened by an increase in the individual medical burden due to the advances in medical technology or health insurance reform.

I also note that the healthcare system and medical services in the actual economy are more complex than this paper has assumed: high-cost medical expense benefits (*kogaku ryoyohi seido*), medical deductions (*iryohi kojo*), private health insurance. In addition, in this paper, I abstract from the long-term care insurance system. In general, the average expenditure for long-term care is much higher than that for medical care. It would be important to incorporate these systems into the model and to precisely capture the medical burden of households, in assessing the impact of the economic structural changes on the bond return, capital return, and the risk premium. These extensions are left for future research.

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Appendix

A Calculation of Medical Expenditure Profiles

In this paper, I compute age- and health-dependent medical expenditure as follows. First, using the population distribution by age and health group reported by Fukai et al. (2018), I calculate the population share of those with "good" health and "bad" health. Their paper classified people into five health groups according to annual medical expenditure: 0-7,800 yen for Q1 (best health condition), 7,801-24,000 yen for Q2, 24,001-54,000 yen for Q3, 54,001-266,999 yen for Q4, and 267,000 yen and over for Q5 (worst health condition). I assume that "good" and "bad" health groups in my model correspond to Q1-Q4 and Q5 groups in their paper.

Next, by combining the population share with the distribution of medical expenditure by age group, I calculate medical expenditure by age and health group. Fukai et al. (2018) also present the average medical expenditure in the percentiles of each age group: 1%, 5%, 10%, 25%, 50%, 75%, 90%, 95% (top 5%), and 99% (top 1%). First, in all age groups, I linearly interpolate these medical expenditures and obtain the medical expenditure by health group. Second, I linearly interpolate the medical expenditure of each age group over age and then obtain the age- and health-dependent medical expenditure.

However, there was a gap between these calculated medical expenditures and average health care expenditure in 2014 reported by the MHLW. For this reason, finally, given the health distribution, I recalibrate the medical expenditures in the model so that they match the actual medical costs.

B Computational Algorithm

In this section, I describe detailed algorithms to compute the steady state. The numerical method of the stationary equilibriums is basically the same as Huggett (1996). For example, consider the steady state under the benchmark policy. We find a set of capital-labor ratio K/N that leads to the equilibrium prices $\left\{r_j^k, w\right\}$, government expenditure G/Y that balances the government budget, and return on bond r^b such that bond market is cleared. Computational steps are described below.

1. Guess aggregate capital K^{ini}, aggregate labor supply N^{ini}, bequests beq^{ini}, and

consumption floor $\underline{c}^{ini}$, and calculate factor prices $\{r^k, w\}$. Set initial value of government expenditures of output $(G/Y)^{ini}$ and initial value for return on bond r^b.

2. Given $\{r_j^k, w\}$ and government policies $\{D^s/Y, \tau^c, \tau^l, \tau^k, \tau^b, \theta, \lambda_j\}$, compute policy functions using the Endogenous Grid Method (EGM) backwardly.

3. Compute the population distribution function Φ from policy functions.

4. Using the distribution function, calculate aggregate variables such as capital K^{new}, labor supply N^{new}, bequests beq^{new}, consumption C, and consumption floor $\underline{c}^{new}$ and bond demand D^d.

5. Find the government spending output ratio $(G/Y)^{new}$ so that the budget constraint of the government sector holds.

6. First, check if K^{ini}, N^{ini}, beq^{ini}, $\underline{c}^{ini}$, and $(G/Y)^{ini}$ are close to K^{new}, N^{new}, beq^{new}, $\underline{c}^{new}$, and $(G/Y)^{new}$, respectively.

7. Second, check if the bond demand D^d is equal to bond supply D^s.

8. If both of the above checks pass, stop the computation. Otherwise, update the initial values, and restart from Step 2.