Effect of Population Ageing in an Overlapping Generation Model with Endogenous Health Care *

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Abstract

The problem of population ageing has long been the center of focus in efforts of curbing the ever-growing health care expenditure in the United States. This project tries to build an S-period overlapping generations model with endogenous health care, and distinct health care versus non-health-care markets. We simulate population ageing by feeding differentially weighted demographics into the model. The model is unfinished with unsolved steady state and time path iteration due to time constraint. We expect population ageing to increase the proportions of labor and output in the health care market as opposed to non-health-care market. The rate at which such proportions rise can be informative to prospective policy makers.

keywords: OLG, Endogenous Health Care, Polutation Ageing, Improved Survival.

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1 Introduction

The Center for Medicare and Medicaid Services predicted that the healthcare spending in US is to grow 5.5% annually on average in 2017-2026, and will occupy 19.7% of the economy. These increases will be fundamentally driven by income growth, demographic changes and ageing population (Cuckler et al., 2018). Population ageing has long been identified as a major contributing factor to the increase in healthcare spending. As Mendelson and Schwartz (1993) pointed out, the costs of treating patients over age 65 and over grew more rapidly than their younger counterparts. With the baby boomers fast approaching their retiring age, the window of time to come up with the right policy that can digest the inescapable expansion of Medicare and extra burden of senior care is rapidly closing. In addition, recent technology advancement will increase life expectancy and postpone mortality, which will also add to the burden of health care spending. Barendregt et al. (1997) showed that a cessation of smoking behaviors in fact increases health care spending in that non-smokers tend to live longer as opposed to smokers, which can serve as evidence that prolonged life expectancy will increase health care spending in the long run. Thus, it is in a policy maker' s favor to have a model that can simulate the effect of population ageing on the health care industry and the economy, reflected by indicators like health care good output, interest rate, savings rate, and etc.

1.1 Grossman Model

Grossman (1972) proposed a framework where health care is modeled as depreciative and durable capital good, with an initial endowment. The model reads:

$$H_{t+1} = (1 - \delta)(H_t + I_t)$$

where H is the health as capital good, and I stands for investments in health. The outcome of health comes twofolds, one enters the utility function as humans enjoy good health, while the other one is reduced amount of sick time, which makes room for more work and leisure time. Due to its uniqueness at the time of its proposal, the Grossman model soon established itself to be the premiere model for demand for health, and found some level of empirical evidence and a range of applications (Cropper, 1981; Corman and Grossman, 1985; Leu et al., 1991; Grossman et al., 1972). However, the Grossman model does not meet critics' expectations of empirical validity. The idea behind its failure to map onto the real world lies in the fact that healthy people with a higher endowment of health capital good, tend to invest less in health but still inherit better health outcome from the last period, than those in poor health. Also, traditionally healthy people are usually more efficient producers of health care, and thus face a lower shadow price of health capital good (Wagstaff, 1986; Zweifel, 2012; Wagstaff, 1993). Despite these shortcomings, the dynamic nature of Grossman model makes it an ideal candidate to incorporate into an overlapping generations model, where decision from the last period affect the agent's optimized decision this period. In this case, the agent can not only choose consumption and savings, but also the amount of investment in health care, which will not only make her a happier person, but also a more productive worker.

1.2 Endogenous Health

The idea of endogenous health care is by no means a strange one. This project will draw inspirations from a couple of recent ones.

Leung and Wang (2010) introduces a two-period model where agents optimize based on the following constraints (1, 2):

$$c_t^t = w_t - s_t - m_t \tag{1}$$

$$c_{t+1}^t = R_t s_t, \quad \text{where} \tag{2}$$

$$R_t = \frac{1 + r_{t+1}}{p(m_t)}, \quad \text{and} \tag{3}$$

$$p(m_t) = p_0 + \bar{p}\sqrt{\frac{m_t}{1 + m_t}} \tag{4}$$

Here, expenditure on health care m_t will increase the agent's chance of surviving to the next period $p(m_t)$. $\bar{p}$ is the maximal chance of survival, which can be increased by technological advancement (3). R_t is the average return on investment (2). Their simulation shows health care to be growth promoting and welfare improving, especially in countries with advanced biomedical technologies.

Hashimoto and Tabata (2010) took one step further, and separated health care industry from non-health care industry. The model makes the assumption that the health care industry is a labor-intensive one, and thus needs no capital input. A_t here stands for labor augmenting factors.

$$Y_t^H = A_t^H L_t^H \tag{5}$$

$$Y_t^N = FK_t, A_t^N L_t^N \tag{6}$$

It also makes the assumption that the labor market is competitive, and thus eventually the wage in non-health care industry equals the wage in health care industry. Eventually, the relative price of health care good satisfies

$$q_t = \bar{w}\frac{A_t^N}{A_t^H} \tag{7}$$

They find that population ageing induces a shift in labor supply from non-health care industry to health care industry, and lowers per capita income growth rate.

Similar studies, mostly two-period models, tell different stories. Fougère et al.

(2007) also studies the effect of population ageing on the economy with a multi-industry setup in their OLG model. They found similar results as (Hashimoto and Tabata, 2010) in that a labor supply shock will lead more labor to health care industry and less labor in other industries. Cipriani (2014) added a pay-as-you-go pension system to OLG and showed that an ageing population resulted from increased longevity will decrease pension payout. Aísa et al. (2004) allows for not only endogenous quantity of health care, but also quality, to probe the dynamic bidirectional relationship between longevity and economics, mediated by human capital accumulation. Galama et al. (2013) relaxes the assumption that the agent makes optimal decision regarding her health, and make the decision to retire an endogenous one. They found that healthier workers do choose to retire later and their health deteriorates more slowly.

The model presented in this project will learn from the two-period models in previous literature, and allow the agents in the model to live for S number of years. Adding this layer of granularity will allow us to see how the income and health level change within the agent's lifetime.

2 Model

In this section I will introduce a OLG model where agents live S periods and labor supply is exogenous. The model will rely heavily on Professor Richard Evans' OLG model with demographic dynamics and exogenous labor (Evans and DeBacker, 2018). In compliance with Grossman Model, the agent will choose an optimized amount of health expenditure, in addition to consumption and savings as specified in Professor Evan's model, to maximize her utility. Improved health will also make her a more productive worker.

2.1 Demographics

Following Evans and DeBacker (2018), the demographic profile evolves according to the following rules

$$\omega_{1,t+1} = (1-\rho_o)\sum_{s=1}^{E+S} f_s\omega_{s,t} + i_1\omega_{1,t}, \quad \forall t \tag{8}$$

$$\begin{gathered}\omega_{s+1,t+1} = (1-\rho_s)\omega_{s,t} + i_{s+1}\omega_{s+1,t}, \\ \forall t \quad \text{and} \quad 1 \leq s \leq E+S-1\end{gathered} \tag{9}$$

$$N_t = \sum_{s=1}^{E+S}\omega_{s,t} \qquad \tilde{N}_t = \sum_{s=E+1}^{E+S}\omega_{s,t} \tag{10}$$

$$g_{n,t+1} = \frac{N_{t+1}}{N_t} - 1 \qquad \tilde{g}_{n,t+1} = \frac{\tilde{N}_{t+1}}{\tilde{N}_t} - 1 \tag{11}$$

$$n_{s,t} = \begin{cases} 1, & E+1 \leq s \leq E + round(\frac{2S}{3}) \\ 0.2, & s \geq E + round(\frac{2S}{3}) \end{cases} \tag{12}$$

Here, $\omega_{s,t}$ stands for the number of households of age s alive at time t. E stands for the amount of time the agent spends in preparation for labor, and S stands for the time post-education and before death. 8 writes the number of newborns at time $t+1$ as the sum of immigration and childbirth at time t. 9 writes the population, barring newborns, at time $t+1$, as the surviving agents and immigrants from time t. ρ_s stands for mortality rate at age s. 10 sums up the all households in the population to be the participating labor force, where N_t is the total population in the economy $\tilde{N}_t$ is the working age population. 11 calculates the total population growth rate g_t and working population growth rate $\tilde{g}_t$. 12 specifies two-thirds of a person's lifetime $\frac{2S}{3}$ to be the retiring age, before which the agent can contribute 1 unit of labor and after which she can only contribute 0.2 unit of labor.

2.2 Firm

Borrowing Hashimoto and Tabata (2010)'s idea, here I also make the distinction between a market for health care goods, and a market for non-health-care goods.

Similar to Hashimoto and Tabata (2010), we make the assumption that the health care market is only labor-intensive. Empirical evidence also supports such assumption: Kocher and Sahni (2011) reports that 56% of all health care spending in the United States go to health care workers, mainly for their non-substitutability. Suppose the price of non-health-care goods is numeraire, and the price of health care good is p_t^H at time t. The productivity functions then become:

$$Y_t^H = A^H(e^{g_y} L_t^H) P_t^H \tag{13}$$

$$Y_t^N = A^N(K_t)^\alpha (e^{g_y} L_t^N)^{(1-\alpha)} \tag{14}$$

Here we make the assumption that the productivity of labor is growing at a constant rate g_y due to technological changes.

The companies in the two markets then will optimize the profit according to

$$\max_{L_t^H} P_t^H A^H(e^{g_y} L_t^H) - w_t^H L_t^H \tag{15}$$

$$\max_{K_t^N, L_t^N} A_t^N (K_t^N)^\alpha (e^{g_y} L_t^N)^{(1-\alpha)} - (r_t^N + \delta) K_t^N - w_t^N L_t^N \tag{16}$$

Here δ is the depreciation rate for capital, while r_t and w_t are the price of capital and wage at time t.

We make the assumption that both the health care and non-health-care markets are perfectly competitive with no barriers to entry, and thus the wages become the same.

$$w_t^H = w_t^N$$

Based on 15 and 16 we can get r_t, w_t and P_t^H.

$$r_t = \alpha A_N (\frac{L_t^N}{K_t})^{(1-\alpha)} - \delta \tag{17}$$

$$w_t = A_N (1-\alpha)(\frac{K_t}{L_t^N})^{\alpha_N} \tag{18}$$

$$P_t^H = \frac{w_t}{A_H} \tag{19}$$

2.3 Households

$$n_{s,t} = n_s \tag{20}$$

$$c_{s,t} + b_{s+1,t+1} + P_t^H h_{s,t} = (1+r_t) b_{s,t} + w_t n_{s,t} f(h_{s-1,t-1}) + \frac{BQ_t}{\tilde{N}_t} \tag{21}$$

$$U = \frac{c^{(1-\sigma)}}{1-\sigma} + \frac{h^{(1-\gamma)}}{1-\gamma} \tag{22}$$

Labor is exogenous in this model (20). 21 states the budget constraint, where $f(h_{s-1,t-1})$ is a boost to productivity, that augments $n_{s,t}$. Here BQ stands for the bequest that dead agents evenly distribute to other living agents. The agents derive utilities from both consumption and health care, in accordance to 22. The households in the economy then optimize according to:

$$\max_{\substack{\{c_{s,t+s-1}, h_{s,t+s-1}\}_{s=E+1}^{E+S}, \\ \{b_{s+1,t+s}\}_{s=E+1}^{E+S-1}}} \sum_{s=E+1}^{E+S} \beta^{s-E-1} [\Pi_{n=E}^{s-1}(1-\rho_n)] U(c_{s,t+s-E-1}, h_{s,t+s-E-1}) \quad \forall s,t$$
$$s.t. \quad 20 \quad \text{and} \quad 21, \quad \text{and} \quad b_{E+1,t}, b_{E+S+1,t} = 0 \quad \forall t \quad \text{and} \quad c_{s,t} \geq 0 \quad \forall s,t \tag{23}$$

The $\Pi_{n=E}^{s-1}(1-\rho_n)$ stands for the cumulative probability of surviving to the next period. This optimization will give two systems of $S-1$ Euler Equations:

$$\frac{\partial U(c_{s,t},h_{s,t})}{\partial c_{s,t}} = \beta(1+r_{t+1})(1-\rho_s)\frac{\partial U(c_{s+1,t+1},h_{s+1,t+1})}{\partial c_{s+1,t+1}} \tag{24}$$

$$\beta(1-\rho_s)w_t n_s \frac{\partial f(h_{s,t})}{\partial h_{s,t}}\frac{\partial U(c_{s+1,t+1},h_{s+1,t+1})}{\partial c_{s+1,t+1}} = P_t^H \frac{\partial U(c_{s,t},h_{s,t})}{\partial c_{s,t}} + \frac{\partial U(c_{s,t},h_{s,t})}{\partial h_{s,t}} \tag{25}$$

$$\forall t, \text{and } E+1 \leq s \leq S-1$$

2.4 Market Clearing

Here, the labor market, capital market, and both the health care good and non-health-care good market have to clear.

$$K_t = \sum_{s=E+2}^{E+S} (\omega_{s-1,t-1}b_{s,t} + i_s\omega_{s,t-1}b_{s,t}) \tag{26}$$

$$L_t^N + L_t^H = \sum_{s=E+1}^{E+S} \omega_{s,t}n_s f(h_{s-1,t-1}) \tag{27}$$

$$Y_t^N = C_t + I_t - \sum_{s=E+2}^{E+S} i_s\omega_{s,t}b_{s,t+1} \quad \text{where} \tag{28}$$

$$I_t = K_{t+1} - (1-\delta)K_t \quad \text{and,}$$

$$C_t = \sum_{s=E+1}^{E+S} \omega_{s,t}c_{s,t}$$

$$Y_t^H = \sum_{s=E+1}^{E+S} \omega_{s,t}h_{s,t} \tag{29}$$

$$BQ_t = (1+r_t)\sum_{s=E+2}^{E+S} \rho_{s-1}\omega_{s-1,t-1}b_{s,t} \tag{30}$$

The capital existent in the market is the sum of savings of living agents and the savings brought by immigrants (26). The existing labor is split between non-health-care and health care industries (27). By Walras' Law, the goods market for non-health-care goods clear trivially (28), while the health care goods market clears only when the supply for health care is equal to the demand, which is the aggregate health care spending by the living agents (29). The aggregate bequest is the sum of savings of the dying agents from the last period (30).

3 Calibration

3.1 Demographics

The calibration for demographics strictly follows the one detailed in Evans and DeBacker (2018). The calibration of fertility rate is based on the 2013 US fertility data reported in Martin et al. (2015), using cubic spline interpolation (Figure 1). The calibration for mortality rates is based on the US morality rate data from Actuarial Life Tables of the U.S. Social Security Administration Bell and Miller (2015) (Figure 2). Finally, we base our calibration for immigration on Bureau (2015) (Figure 3). Following a Markov process described in Evans and DeBacker (2018), we can get the transition path and steady state of demographics (Figure 4), which will be the ω_s in the model.

3.2 Labor Boosting by Health Care

Here I use OECD countries' health care spending (OECD, 2014b) VS labor productivity data (OECD, 2014a) as a proxy for how much a marginal dollar on health care can boost labor productivity. As mentioned before, empirically, there are many confounding factors that decide how much a country spends on health care. The effect of health care on productivity exhibited by the regression here by no means exhibits a causal effect of great significance. However, here I am using it as a rudimentary calibration of $f(h_{s-1,t-1})$ that appeared in 26, namely how much the endogenous health care spending can boost labor productivity. The correlation between health care spending and labor productivity is negative (Figure 5). One fix of this empirical conundrum can be a regression. Here I included the most easily available covariate, the GDP of the country. As shown in Figure 6, after controlling for GDP, there are a couple of years where $\beta_{HealthCare}$ is positive (Table 1). The average of $\beta_{HealthCare}$ for the positive years, excluding year 2009, due to the financial depression, 2.280. For tractability, here I assume linearity for the boost of health care spending on productivity.

$$f(h_{s-1,t-1}) = 1 + \zeta h_{s-1,t-1} \tag{31}$$

After calibration, I assume $\zeta = 2.28$

Table 1: Years with Positive $\beta_{HealthCare}$

Year	$\beta_{HealthCare}$
1995	0.196
1996	2.302
1997	2.355
1998	1.428
2001	1.245
2002	3.155
2003	2.303
2004	3.167
2005	4.350
2009	12.374

Source: (OECD, 2014b) & (OECD, 2014a)

4 Equilibrium and Solution

4.1 Stationalization at Equilibrium

In this model, the economy is growing due to two sources: one is the constant labor augmenting technological change g_y, and one is the population growth $\tilde{g}_{n,t}$, defined in 11. Let the hat notation indicate the variable after stationalization, the market clearing conditions then become:

$$\hat{K}_t = \frac{1}{1+\tilde{g}_{n,t}} \sum_{s=E+2}^{E+S} (\hat{\omega}_{s-1,t-1}\hat{b}_{s,t} + i_s\hat{\omega}_{s,t-1}\hat{b}_{s,t}) \tag{32}$$

$$\hat{L}_t^N + \hat{L}_t^H = \sum_{s=E+1}^{E+S} \hat{\omega}_{s,t} n_s f(h_{s-1,t-1}) \tag{33}$$

$$\hat{Y}_t^N = \hat{C}_t + \hat{I}_t - e^{g_y} \sum_{s=E+2}^{E+S} i_s\hat{\omega}_{s,t}\hat{b}_{s,t+1} \quad \text{where} \tag{34}$$

$$\hat{I}_t = e^{g_y}(1+\tilde{g}_{n,t+1})\hat{K}_{t+1} - (1-\delta)\hat{K}_t \quad \text{and,}$$

$$\hat{C}_t = \sum_{s=E+1}^{E+S} \hat{\omega}_{s,t}\hat{c}_{s,t}$$

$$\hat{Y}_t^H = \frac{1}{1+\tilde{g}_{n,t}} \sum_{s=E+1}^{E+S} \hat{\omega}_{s,t}\hat{h}_{s,t} \tag{35}$$

$$\hat{BQ}_t = \frac{1+r_t}{1+\tilde{g}_{n,t}} \sum_{s=E+2}^{E+S} \rho_{s-1}\hat{\omega}_{s-1,t-1}\hat{b}_{s,t} \tag{36}$$

The clearing prices then become:

$$\hat{r}_t = \alpha A_N (\frac{\hat{L}_t^N}{\hat{K}_t})^{(1-\alpha)} - \delta \tag{37}$$

$$\hat{w}_t = (1-\alpha) A_N (\frac{\hat{K}_t}{\hat{L}_t^N})^{\alpha} \tag{38}$$

$$\hat{P}_t^H = \frac{\hat{w}_t}{A_H} \tag{39}$$

At equilibrium, the following conditions must be satisfied:

- Households optimize according to 24 and 25;
- Firms optimize according to 37 to 39;
- Market clears according to 32 to 36

4.2 Solution

4.2.1 Steady State

For steady state solution, we will guess the stationary price of capital $\bar{r}$ and the bequest $\bar{BQ}$. From $\bar{r}$ we can get $\bar{w}$, expressed as

$$\bar{w}_t = (1-\alpha)A_N(\frac{A_N}{\bar{r}} + \delta)^{\frac{\alpha}{1-\alpha}}$$

With $\bar{w}$ we can get $\bar{P}_H$. From the stationary prices, we can get vectors of consumption $\bar{c}_s$, $\bar{b}_s$, and health care spending $\bar{h}_s$. To get these, I first guess the first period consumption $\bar{c_1}$, then I propagate a vector of $\bar{c_s}$ based on the Euler equations of 24. Then, plugging in $\bar{c_s}$, I try to get a vector of $\bar{h_s}$ by minimizing the errors in the $S-1$ Euler Equation of 25. Finally, I get a vector of $\bar{b_s}$ by plugging into the budget constraint in 21. With the three vectors in hand, I update $\bar{c_1}$ make the last-period savings $\bar{b}_{E+S+1}$ to be zero using an error minimizer. To reach the steady state, I update my guess of $\bar{r}$ and $\bar{BQ}$ until the system reaches steady state.

Unfortunately, I have not been able to solve the steady state yet. However, Figure 7 reflects the expected steady state result. When the agent is young, she would want to invest more in her health to be a more productive worker. As she grows old, she would save more and decide to spend less on health care. As she reaches retirement age, she would choose to save less and spend more on health care in expectation of longevity.

4.2.2 Time Path Iteration

The time path iteration solution will resemble the steady state solution, except that instead of guessing $\bar{r}$ and $\bar{BQ}$, we will guess $\{\hat{r}_1^i, \hat{r}_2^i, \hat{r}_3^i...\hat{r}_T^i\}$ and $\{\hat{BQ}_1^i, \hat{BQ}_2^i, \hat{BQ}_3^i...\hat{BQ}_T^i\}$, where T is the necessary number of period for the system to reach the derived steady state. The updates will follow the same protocol as described in steady state solution.

5 Simulation and Expected Results

For simulation of population ageing, I weigh the demographics exhibited in Figure 4 more heavily on the elderlies, resulting in the new demographics as shown in Figure 8. I expect the health care spending to increase in general, but more heavily as the agent grows old, as elder people usually need more care than young people, as shown in Figure 9. Similar trend is expected for time path iteration results.

6 Conclusions and Future Directions

Due to time constraints, the model is largely unfinished with unsolved steady state and time path iteration. My expected results would predict more labor allocated to the health care industry as opposed to non-health-care industry. In other words, $\frac{Y_H}{Y_H+Y_N}$ will increase and rise more rapidly over T, under population ageing, congruent with the ever-increasing percentage of health care spending in US. Similarly, $\frac{L_H}{L_H+L_N}$ will also rise under population ageing, but at a more steady pace. These results should prepare the policy makers with an approximate rate at which both the output and labor will rise in near future.

In addition to solving the steady state and time path iteration, there are several future directions that this project can partake.

First, I can convert labor to be an endogenous decision. That way, the agent will have to make four decisions within each period: $c_{s,t}, b_{s,t}, h_{s,t}$ and $n_{s,t}$. Leisure will enter the agent's utility function. Adding endogenous labor will give a more accurate depiction of how increased productivity can affect agent's labor decision.

Second, the calibration of $f(h_{s-1,t-1})$ could benefit from more fine-grained micro-level panel data. Ideally, I could run a fixed effect regression at an individual level, instead of a crude regression at the country level to get a more accurate $\beta_{HealthCare}$.

Third, $f(h_{s-1,t-1})$ can be modeled endogenously into the demographics, as increased chance of survival into the next period. This way, the demographics can no longer be solved in a static Markov process. However, the dynamic demographics will give a more accurate depiction of the increased chance of survival as a function of health care spending.

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List of Figures

Figure 1: Fertility Rate Calibration

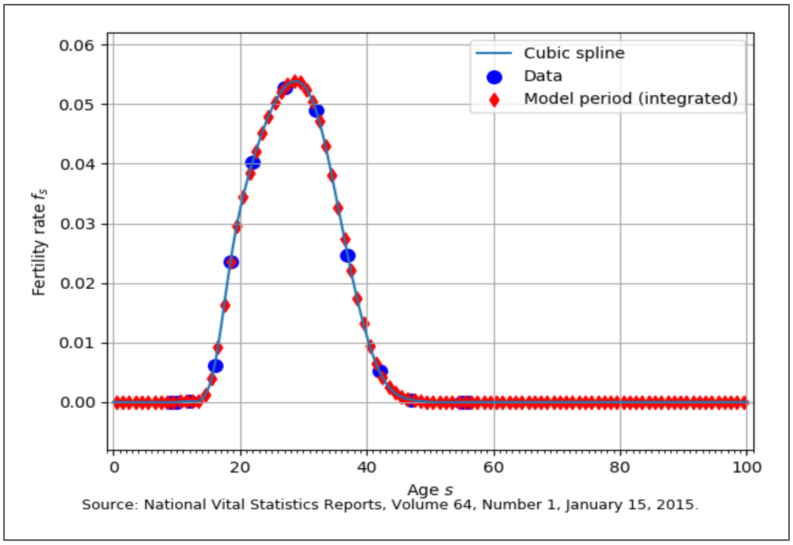
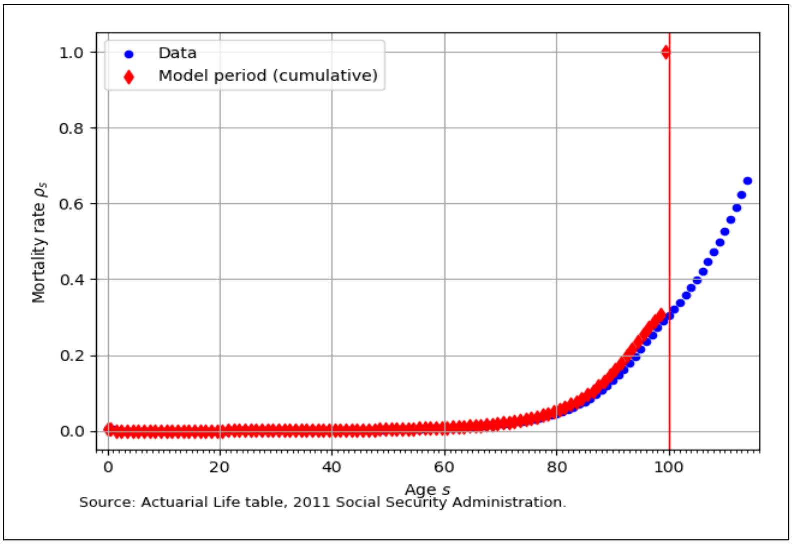


Figure 2: Mortality Rate Calibration



Source: Actuarial Life table, 2011 Social Security Administration.

Figure 3: Immigration Rate Calibration

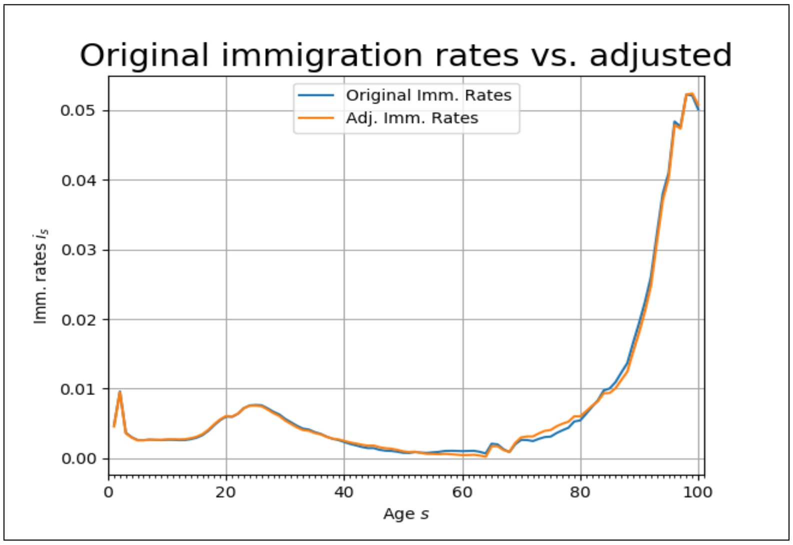


Figure 4: Calibrated Demographics

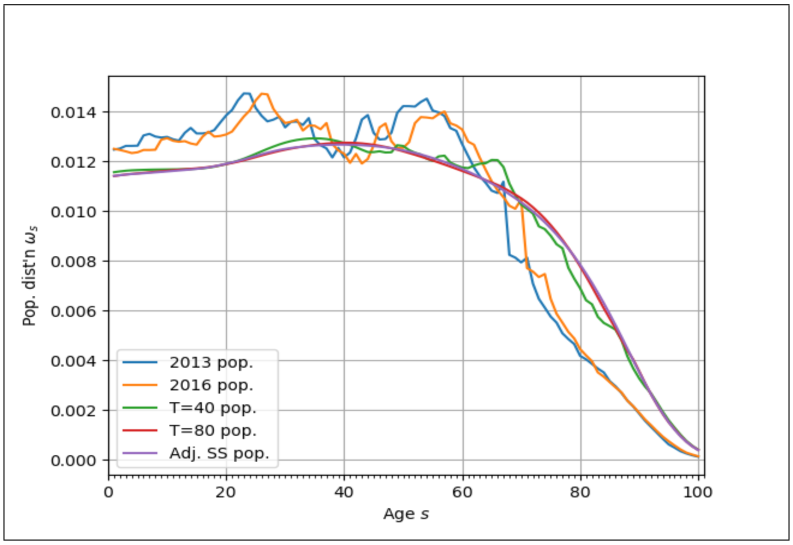


Figure 5: Correlation between Health Care Spending and Productivity in OECD countries

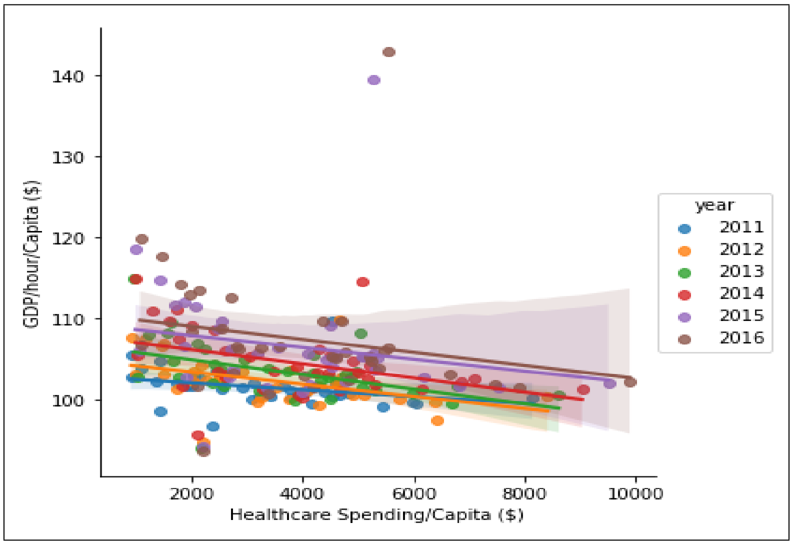


Figure 6: Boost of Productivity by Healthcare over Time in OECD countries

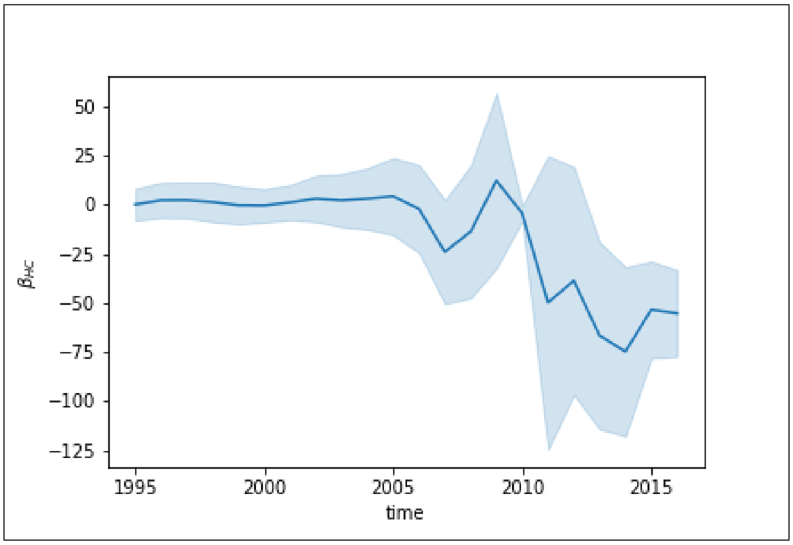


Figure 7: Expected Steady State Result

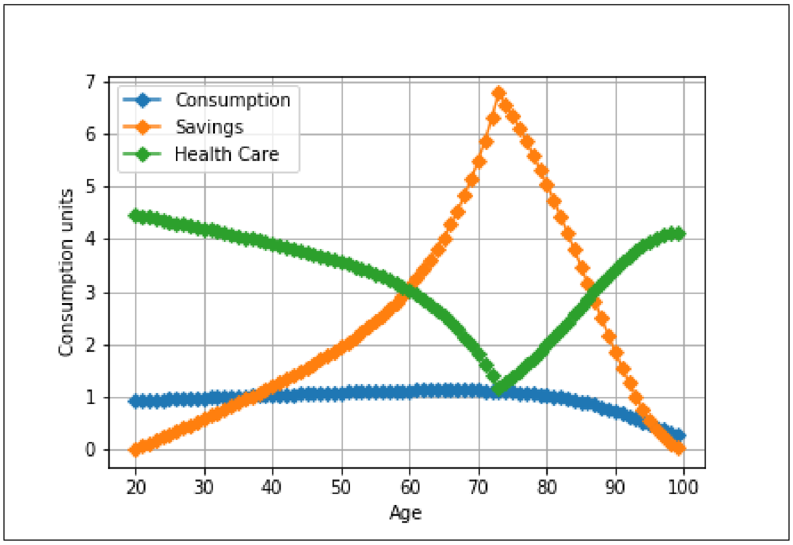


Figure 8: Simulation of Population Ageing

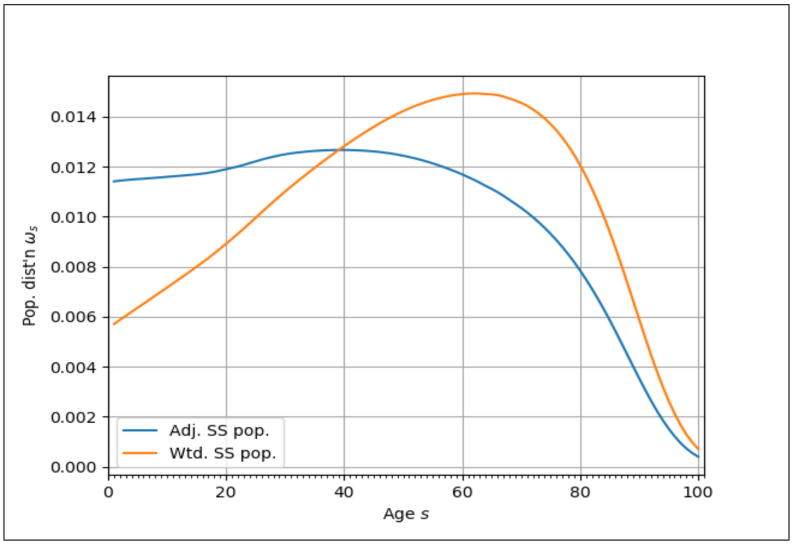


Figure 9: Expected Steady State Result with Population Ageing Simulation