THE RISE IN MEDICAL EXPENDITURES AND LONG-RUN MACROECONOMIC OUTCOMES

by

Mark C. Kelly

(Under the Direction of Santanu Chatterjee)

Abstract

In recent decades medical expenditure growth in the US has significantly outpaced output growth, threatening to crowd out investment, consumption, and discretionary government expenditures. Recent health care reforms, such as the Affordable Care Act, were instituted in part to curtail the growth of medical expenditures. However, the long-run economic ramifications of this sort of cost containment health care reform is still up for debate. This thesis is laid out as follows: In Chapter 2, I utilize a novel general equilibrium model with health capital accumulation and health insurance to analyze the long-run macroeconomic consequences of one-time shocks to the economy that are related to the growth in health care expenditures. Then, in Chapter 3, I develop a continuous time overlapping generations model with exogenous mortality to test the macroeconomic implications of various health care and fiscal policy reforms. This model is extended in Chapter 4 to allow for endogenous mortality. The analysis contained in Chapters 2-4 emphasizes the importance of accounting for changes to productivity and economic growth when evaluating the aggregate consequences of a particular health care reform.

Index words: Health Insurance; Medical Consumption; Health Care Reform; Neoclassical Growth Model; Continuous Time Overlapping Generations Model; Endogenous Growth Theory.

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To my wife Emily

Ephesians 1:7-10

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Chapter 1

Introduction

> "Spending on health care strains both household and government budgets throughout the world. In many countries, health expenditure per capita has risen faster than the rise in GDP per capita. Consequently, health care costs have taken an ever-increasing share of government, employer, and household budgets and put pressure on those financing the burden of health care (through taxes or insurance contributions). Looking ahead, there are concerns in many industrial countries that an ever increasing share of the government budget spent on health care (OECD [2006]) will crowd out resources for other important public goods and publicly provided services." (Hsiao and Heller [2007])

Between 1960 and 2013, average annual growth of real personal health care[1] expenditures outpaced real GDP growth by more than 2.3 percentage points, transforming the health care sector into one of the most important sectors in the economy, employing about 11 percent of the labor force, and accounting for over 17 percent of GDP. As Hsiao and Heller (2007) note, there is growing concern that the persistent rise in medical expenditures will eventually restrict wage growth and crowd out non-medical consumption, investment, and discretionary government spending.

[1] "The total amount spent to treat individuals with specific medical conditions." *Centers for Medicare and Medicaid Services (2011a).*

However, as Newhouse (1992) asserted, in most circumstances, the emergence of a high growth industry would not be alarming, but would be viewed as a beneficial development. Nevertheless, there are several inefficiencies and market failures associated with health care and health insurance markets, such as moral hazard and adverse selection,[2] that result in potentially significant welfare losses from the non-optimal over-consumption of health care. Rising demand for health care services and the tax-exempt status of health insurance benefits amplify these welfare losses, providing the impetus for cost containment health care reform (see Pauly [1986]).

A weakness of the early literature on asymmetric information in health insurance markets was its adherence to static, one-period models that ignore advancements in medical technology and income growth. This flaw was exposed by Newhouse (1992), who concluded that the tax exemption for employer-provided health insurance benefits is unable to explain much of the rise in spending levels over time, even though it may be able to account for why current levels of health care spending are as high as they are. Ultimately, he finds that medical technology growth is the most important determinant of medical expenditure growth.

Similarly, Hall and Jones (2007) developed a dynamic overlapping generations (OLG) model to show that increasing the health investment share of income is the optimal response to rising income levels. These two studies demonstrate that, despite the aforementioned welfare losses associated with health insurance markets, a significant portion of the health care spending growth can be explained by optimal responses to changing economic conditions. However, if the welfare losses arising from moral hazard and the subsidization of employer-provided health insurance are substantial enough, a rise in the income share of medical expenditures may still have adverse aggregate consequences, even if it is the result of optimal household decision-making.

[2]See Pauly (1986), Feldman and Dowd (1991), and Rothschild and Stigliz (1976).

Unfortunately, since Newhouse (1992) lacks a formal theoretical framework and Hall and Jones (2007) does not include health insurance, neither study is able to account for these welfare losses. Consequently, there is still considerable uncertainty about what affect the rise in medical expenditures will have on the economy in the long-run. Addressing this gap in the literature is one of the primary goals of this dissertation.

In Chapter 2, I develop a general equilibrium model with tax exempt employer-provided health insurance and a public medical consumption subsidy to investigate the aggregate consequences of several one-time shocks to the economy that affect the steady-state consumption of medical services. The advantage of the general equilibrium framework is that it allows me to isolate the effect of individual determinants of the rise of health care demand,[3] while simultaneously accounting for the health benefit tax exemption, moral hazard, and positive productivity externalities associated with health investment.

From this model I can conclude that an increase to either final goods or health investment productivity will result in an increase of total output, physical capital, and medical and non-medical consumption, leading to improved aggregate welfare. In contrast, an increase in the depreciation rate of health reduces social welfare as aggregate output, physical capital, labor supply, and consumption of medical and non-medical goods all decline. Similarly, a decline in the out-of-pocket cost of health care raises steady-state investment in health, which increases the health capital stock, raising output. However, non-medical consumption and leisure time both fall, resulting in a reduction of aggregate welfare, despite the rise in medical consumption and health capital.

The general equilibrium framework has two important limitations; 1) There is a single infinitely-lived representative household, preventing the model from making any predictions with respect to longevity, and 2) economic growth is exogenous. Life extension is the primary

[3]i.e. Health care and final goods productivity, the magnitude of health capital depreciation, or aggregate measures of public and private generosity.

motivation for health investment and has a major impact on lifetime utility. Similarly, the growth rate of output is a significant determinant of long-run aggregate welfare growth. Health care reform affects aggregate medical consumption, which in turn affects economic growth, longevity, and ultimately aggregate welfare. Consequently, in order to accurately understand the economic impact of health care reform, one must account for both endogenous output growth and mortality.

Endogenous mortality is a common feature of many of the recent studies of health care reform. Endogenous growth models, on the other hand, are largely absent in this literature. Therefore, in Chapters 3 and 4, I construct a continuous time OLG model with endogenous growth and mortality to examine the effect of health care reform and fiscal policy on output growth and social welfare. More specifically, I assume that output is generated using a version of the AK model developed by Romer (1986) augmented by government infrastructure spending as in Barro (1990). This production technology implies that there is an interaction between government infrastructure spending and the capital-labor ratio generates a productivity externality that results in endogenous growth. The equilibrium economic growth rate is partially determined by medical consumption, allowing me to evaluate the effects of health care reform on long-run growth and welfare.

The OLG model supports four main conclusions. First, medical consumption has a small, but positive effect on mortality, with health investment productivity being the main determinant of longevity. Second, if households are homogeneous, health care reforms that lower the average out-of-pocket cost share of medical consumption will reduce output growth and aggregate welfare. Third, cutting government consumption to accommodate increased public medical expenditures improves economic growth and welfare, while reductions to government investment will have the opposite effect. Finally, raising the Medicare eligibility age from 65 to 67 will decrease the public share of health care expenditures, but it also has an adverse effect on output growth and welfare when life annuities are present.

Chapter 2

Health Insurance and the Macro Economy: A Neoclassical Approach

2.1 Introduction

The elevated growth rate of health care expenditures throughout the last several decades is one of the most significant and challenging macroeconomic phenomena facing most modern industrial nations. Between 1960 and 2013, the share of GDP due to real personal health care (PHC)[1] expenditures in the US increased by a factor of over 3, rising from 4.3 percent in 1960 to 14.7 percent in 2013. Naturally, there has been increasing concern over the sustainability of the current growth trend of medical expenditures, leading to calls for health care reforms aimed at curtailing the growth of medical expenditures (see Auerbach, Gokhale, and Kotlikoff [1992] and Hsiao and Heller [2007]). In response to these concerns, there have been numerous studies dedicated to identifying the underlying factors that are driving the expansion of the health care sector. Unfortunately, macroeconomic analyses of the long-run aggregate consequences of the rise in medical expenditures have been largely absent.

[1]See description of PHC in Chapter 1

Despite the widespread support for cost containment policies aimed at slowing the expansion of the health care sector, there is still some debate about the urgency of such reforms. The majority of studies that investigate rising medical expenditures utilize micro models that concentrate on the welfare losses that result from market failures in the health care and health insurance markets.[2] Other studies, such as Newhouse (1992) and Hall and Jones (2007), demonstrate that a portion of the rise in medical expenditures can be explained by optimal household responses to changes in the economy. Consequently, there is still some uncertainty regarding the ultimate impact the continued rise in medical expenditures will have on the overall economy.

Thus, there is a need for a theoretical analysis of the rise in medical expenditures that is capable of incorporating important trade-offs associated with health investment that occur in the aggregate. Therefore, in what follows I develop a benchmark neoclassical model that is useful for investigating the aggregate steady-state response to changes in the economy that are related to the growth of the health care sector. Specifically, I adapt the standard Neoclassical growth model with endogenous labor supply to include health capital accumulation following Grossman (1972). Health investment is financed in part by employer-provided private health insurance as well as a government subsidy. I assume that the household does not internalize the impact it has on the rate of depreciation of health capital, generating a negative externality that the household will want to insure against.

The analytical model is calibrated to match annual data for the US economy for the period 1996-2013. After calibrating the model and solving for the steady-state numerically, I turn to analyzing the transition dynamics and welfare response of the model to various changes to the economy that have been identified by the health economics literature as being related to the growth in medical expenditures. These scenarios include increases to 1) final goods productivity, 2) medical sector productivity (i.e. new medical technologies), 3) the

[2] e.g. Pauly (1974), Feldman and Dowd (1991), Pauly (1986) and Rothschild and Stiglitz (1976).

rate of health capital depreciation, 4) the private insurance coinsurance rate[3] and 5) the public medical subsidy rate.

The model predicts that productivity increases in both final goods and health investment production raise total output, physical capital, and medical and non-medical consumption, leading to an increase in aggregate welfare. In contrast, an increase in the depreciation rate of health reduces aggregate output, physical capital, labor supply, and consumption of medical and non-medical goods, leading to a decline in social welfare. Similarly, a decline in the out-of-pocket cost of health care results in over-investment in health, reducing aggregate welfare despite a rise in aggregate output and health capital.

In Section 2.2 I describe the growth of medical expenditures, review the medical expenditure growth literature, and discuss the aggregate role of health investment in the economy. Section 2.3 introduces the model. Section 2.4 describes the data sources utilized in the calibration of the model and presents the relevant output ratios and time allocations that the model is calibrated to match. I then discuss the values selected for the parameters in the model and compare the results from the model with the data. In Section 2.5 I analyze the response of welfare to increases to final goods productivity, health investment productivity, the rate of health capital depreciation, the public insurance subsidy rate, and the private coinsurance rate. Then, in Section 2.6 I discuss the transition dynamics that result from the changes in the economy examined in Section 2.5. Finally, Section 2.7 provides conclusions and briefly discusses potential areas for future research.

2.2 Medical Expenditure Growth

While the rapid expansion of medical expenditures is commonplace among industrial nations, no other nation spends as much on health care as the US and few have experienced

[3] I use the term "coinsurance" loosely. In the model, this parameter is not a pure coinsurance rate. Rather it is equal to the fraction of medical expenditures not financed by the private health insurer.

health care sector growth rates commensurate with those experienced in the US. From 1996 to 2013, PHC expenditures in the US grew approximately 1.3 times as fast as real GDP. Consequently, the PHC-GDP ratio rose from 11.38 percent in 1996 to 14.72 percent in 2013. As Figure 2.1 below demonstrates, the rise in the medical expenditures-output ratio is significantly greater than the increase in the non-medical consumption-output and non-medical government expenditures-output ratios.

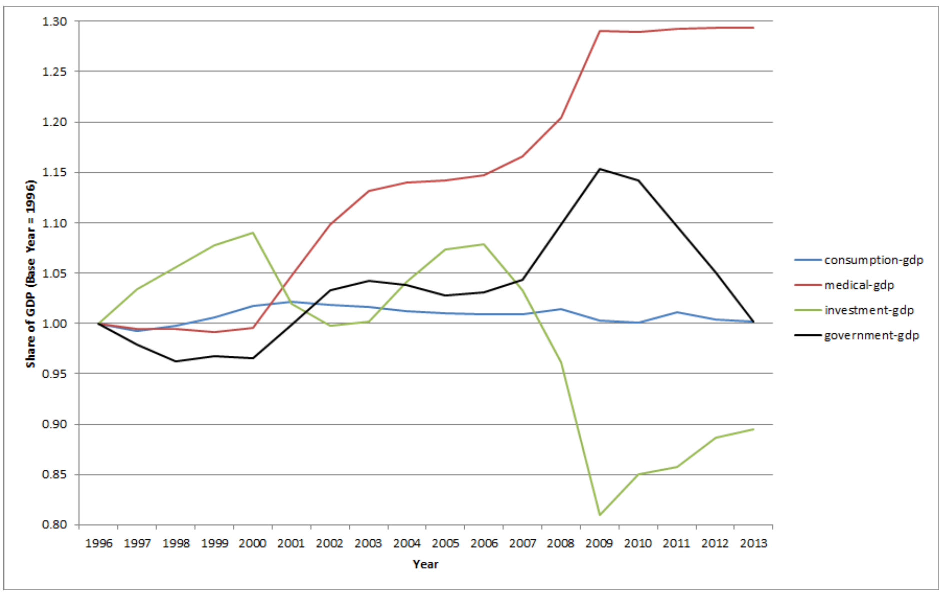


Figure 2.1: Investment, Non-Medical Government Expenditures, Medical and Non-Medical Consumption to Output Ratios (1996-2013)

There is little indication that the expansion of the health care sector is slowing. According to estimates from the Centers for Medicare and Medicaid Services (2011b), National Health Expenditures[4] are expected to increase from 17.9 percent of GDP in 2011 to 19.9 percent in 2022. As a result, there is concern that if medical expenditures continue to outpace output, then non-medical consumption, investment and government spending will be crowded out, reducing social welfare.

[4]Defined as expenditures on medical care that treats specific conditions (i.e. PHC expenditures) plus all other health care related expenditures including R&D investment, public health expenditures, etc..

Given the widespread concerns over the rapid expansion of the health care sector, the health care reform debate has been at the forefront of political discourse in the US since the 1990's. Successful design of health care reform requires a comprehensive understanding of what is driving the growth in medical expenditures, presenting economists with a productive area of research. Newhouse (1992) considered several proposed determinants of health care expansion. After analyzing each of the various proposed factors, he concluded that the rapid advance of medical technology is the most important determinant of medical expenditure growth, potentially accounting for more than half of the rise in medical consumption. Subsequent studies by Cutler et al. (2006) and Skinner and Staiger (2009) link technology growth to improved survival rates and quality of care, thereby increasing the demand for health care, supporting Newhouse's conclusion.

Several other studies followed Newhouse (1992) that attempted to identify additional factors driving the growth of medical expenditures. Hall and Jones (2007) utilized a dynamic OLG model to demonstrate that as incomes rise, households will desire to increase their lifespans. Consequently, the household will trade some non-medical consumption in favor of increased medical consumption, so that, as income levels rise, the optimal response of households is to devote a larger portion of their income to medical consumption. Additional studies, such as Gerdtham and Jonsson (2000), support Hall and Jones' conclusion.

Other important factors contributing to health care expansion include the increase in health insurance access and generosity (Manning et al. [1987]), over insurance resulting from moral hazard (Pauly [1974] and Feldman and Dowd [1991]) and the employer-provided health insurance tax exemption (Pauly [1986]). While all of these factors contribute to the growth of medical expenditures, a recent study by Fonseca et al. (2013) suggests that, when considered in isolation, individual factors are unable to explain much of the rise in expenditures. However, when considering all of these changes together they find that there is a "complementarity effect" that explains most of the growth (i.e. 57 percent).

As Fonseca et al. reveals, the growth of medical expenditures cannot be explained by any one factor. Instead, it is the sum total of many factors. From an aggregate welfare perspective this is an important result as it highlights the need to evaluate medical expenditure growth utilizing a macroeconomic framework that can evaluate the aggregate effect of each of the determinants identified above while accounting the trade-offs associated with health investment that were originally identified in the seminal work by Grossman (1972).

Grossman's model demonstrates that too much investment in health (i.e. both time and income investment) can lead to diminished lifetime utility as labor and leisure time fall and non-medical consumption and savings decline. Too little investment leads to declining life expectancies and quality of health that offset the gains from increased non-medical consumption and leisure time. Consequently, the agent in Grossman's model must determine the optimal allocation of his time between labor, leisure, health investment and sick time while simultaneously determining the optimal allocation of his income between health investment, consumption of market and non-market goods, and savings.

2.3 Model

I assume that the economy is composed of an infinitely-lived representative household, a final goods producer, a medical care provider, a private health insurer, and a government that provides public health insurance (i.e. a medical consumption subsidy) and non-medical consumption. The household is born with a health capital stock that serves two important functions in the economy: 1) it is employed in the production of the final good and 2) it enters the household's utility function.[5] I assume that health capital is subject to two forms of depreciation; fixed depreciation (i.e. aging) that occurs at the rate δ_h and endogenous

[5] This assumption was also used by Grossman (1972). Gerdtham and Johannesson (2001) find evidence that utility is affected both directly and indirectly by health status. Bloom, Canning, and Sevilla (2003) include health as an input in production and find that health has a positive effect on economic development.

health depreciation (i.e. illnesses and accidents), that occurs with a magnitude equal to $\rho(u)$. The latter has two components; an exogenous component $\bar{\rho}$ and an endogenous component that is inversely related to the time the household devotes to maintaining its health (i.e. exercising, preparing healthy meals, going to the doctor's office, etc.). Throughout this paper I will refer to this fraction of time as health maintenance time (u).

I assume that the household does not internalize the effect of u on $\rho(u)$ and therefore treats $\rho(u)$ as exogenous, motivating the household to obtain insurance. Additionally, since the household does not fully internalize u, $\rho(u)$ will be above its optimal level, increasing steady-state medical consumption, leading to higher private health insurance premiums and greater public medical expenditures. This negative externality approximates the problem of moral hazard that exists in health insurance markets.

In addition to mitigating health capital depreciation, health maintenance time also functions as an input in the health investment function alongside consumption of medical services (m). Combining the household's health investment with health capital depreciation, I can define the health capital accumulation function as:

$$\dot{h} = F(m, u) - [\delta_h + \rho(u)]h, \tag{2.1}$$

where endogenous health capital depreciation takes the following functional form:

$$\rho(u) = \bar{\rho}e^{-\mu u};\ \ \mu > 0. \tag{2.1a}$$

In equation (2.1a) $\bar{\rho}$ is the exogenous component of the adverse shock. The health investment production function in equation (2.1), $F(m, u)$, takes the following Cobb-Douglas form:

$$F(m, u) = Bm^{\psi}u^{1-\psi} \tag{2.1b}$$

where B is the health investment productivity parameter and ψ is the share of health investment due to medical services.

I assume that the household treats the depreciation rate of health capital as exogenous. This generates a negative externality that motivates the household to acquire health insurance. The household obtains health insurance through an employer-provided health insurance benefit. Premiums are paid by the employer directly to the private insurer at a rate that is determined by profit maximization in the final goods and insurance sectors. The representative final goods producer maximizes profit as follows:

$$\max_{k,n} \Pi_f = y - rk - (w + \pi)n \tag{2.2}$$

$$\frac{\partial \Pi_f}{\partial k} = \frac{\partial y}{\partial k} - r = 0; \quad r = \frac{\partial y}{\partial k} \tag{2.2a}$$

$$\frac{\partial \Pi_f}{\partial n} = \frac{\partial y}{\partial n} - (w + \pi) = 0; \quad w = \frac{\partial y}{\partial n} - \pi \tag{2.2b}$$

where y is total output, r is the interest rate, k is physical capital, w is the wage rate, π is the premium rate, and n is the fraction of the household's time endowment devoted to labor. Total output is produced with health capital, physical capital, and labor serving as inputs according to the following production technology:

$$y = Ah^{\eta}k^{\alpha}(1 - u - l)^{1-\alpha}, \quad 0 < \alpha, \eta < 1 \tag{2.3}$$

In equation (2.3), A represents total factor productivity, h is the agent's health capital stock, l is the fraction of the agent's time endowment (normalized to 1) devoted to leisure and u is the fraction of the agent's time endowment devoted to health maintenance. Note, however, that the household does not internalize the effect of health capital on output. Consequently, there is a positive externality associated with health investment that may mitigate some of the adverse effects associated with over-investment in health care.

The representative insurer receives premium payments from the final goods firm equal to the product of the premium rate (π) and the household's labor supply ($n = 1 - u - l$). In return, the insurer agrees to finance a fixed fraction (i.e. the actuarial value $1 - b$) of all of the household's health care purchases. Total insurance claims are defined as the product of the actuarial value and total medical consumption. Therefore, the profit function for the insurer is given as:

$$\Pi_I = \pi(1 - u - l) - (1 - b)P_m m, \tag{2.4}$$

where P_m is the price of medical consumption relative to the numeraire price of non-medical consumption and m is household consumption of medical services. For simplicity, I assume that the health insurance market is perfectly competitive so that the insurer will earn zero profit. Solving for the premium rate yields:

$$\pi = \frac{(1 - b)P_m m}{(1 - u - l)} \tag{2.4a}$$

The representative medical provider receives revenue from purchases of medical services and incurs costs, $\phi(m)$. The relative price of medical consumption with respect to the price of non-medical consumption is determined by equilibrium in the health care market. The objective function for the medical provider is defined as:

$$\max_{m} \Pi_m = P_m m - \phi(m), \tag{2.5}$$

where the medical provider's cost function is given as:

$$\phi(m) = m^{\nu}, \quad \nu > 0. \tag{2.5a}$$

This functional form was selected to ensure that the medical provider's variable costs are increasing in m, while the absence of fixed costs guarantees that the medical services market is competitive. Profit maximizing behavior by the medical provider implies that P_m will be determined as follows:

$$\frac{\partial \Pi_m}{\partial m} = P_m - \nu m^{\nu-1} = 0; \quad P_m = \nu m^{\nu-1} \tag{2.5b}$$

In addition to private health insurance, I assume that there is a public health insurance program. In the US public medical expenditures come primarily, though not exclusively, from Medicare (elderly individuals) and Medicaid (low income households). Since this model is intended to be foundational, I have opted to utilize an infinitely-lived representative household framework. Consequently, there are no elderly or low-income households making it impossible to model Medicare and Medicaid as such. However, I contend that in an infinitely-lived framework public health insurance is conceptually equivalent to a subsidy that is equal to a fixed fraction of total medical expenditures. This is a reasonable assumption given the limited variability in the fraction of total medical expenditures financed by the government over the sample period. Moreover, this assumption has the advantage of simplifying the model so that there is a single health care good (as opposed to both a private health care good and public health care good).

All government expenditures are funded by a lump-sum tax/transfer T, as well as taxes on labor and capital income, at rates τ_w and τ_k respectively. In addition to providing the medical subsidy, the government also provides a non-medical consumption good. Total government expenditures are constrained to be equal to a fixed fraction of total output (g). Accordingly, the government's budget constraint is defined as follows:

$$\tau_k rk + \tau_w w(1-u-l) + T = c_g + aP_m m = gy, \tag{2.6}$$

where c_g is non-medical government consumption and a is the fraction of total medical consumption subsidized by the government.

In the household's optimization problem, I assume that the household does not internalize the effect that their consumption of medical services has on the relative price of medical care and the premium rate. Similarly, the household does not internalize the effect that health maintenance time has on ρ. Consequently, moral hazard will exist in both the public and private health insurance sectors.

The household supplies labor and rents physical capital to the final goods firm in return for capital and labor income. With this income the household accumulates physical capital that depreciates at rate δ_k and purchases out-of-pocket medical care and private non-medical consumption goods (c_p). Therefore, the household's budget constraint is given as:

$$\dot{k} = [(1-\tau_k)r - \delta_k]k + (1-\tau_w)w(1-u-l) - c_p - (b-a)P_m m - T \tag{2.7}$$

Finally, the household receives utility from leisure time l, health capital h, and a composite consumption good, c, composed of private medical and non-medical consumption. The household's welfare function is given as:

$$\Omega = \int_0^\infty \left[\frac{(ch^{\theta_h} l^{\theta_l})^\gamma}{\gamma}\right] e^{-\beta t} dt, \quad c = c_p^{\theta_c} m^{1-\theta_c} \tag{2.8}$$

where β, θ_h, $\theta_l > 0$, $0 < \theta_c < 1$, $-\infty < \gamma < 1$, and $1 > \gamma(1+\theta_h+\theta_l)$.

The current-value Hamiltonian that characterizes the household's optimization problem is described in equation (2.9):

$$\begin{aligned}\mathcal{L} = &\left[\frac{(ch^{\theta_h} l^{\theta_l})^\gamma}{\gamma}\right] e^{-\beta t} + \lambda_2 e^{-\beta t}\{Bm^\psi u^{1-\psi} - [\delta_h + \rho(u)]h - \dot{h}\} \\ &+ \lambda_1 e^{-\beta t}\left\{[(1-\tau_k)r - \delta_k]k + (1-\tau_w)w(1-u-l) - c_p - (b-a)P_m m - T - \dot{k}\right\},\end{aligned} \tag{2.9}$$

where λ_1 is the shadow cost of physical capital and λ_2 is the shadow cost of health capital.

Optimization results in the following first-order conditions:

$$\theta_c c_p^{\gamma\theta_c - 1}[m^{1-\theta_c} h^{\theta_h} l^{\theta_l}]^{\gamma} = \lambda_1 \tag{2.10a}$$

$$(1-\theta_c) m^{\gamma(1-\theta_c)-1}[c_p^{\theta_c} h^{\theta_h} l^{\theta_l}]^{\gamma} + \lambda_2 \psi B \left[\frac{m}{u}\right]^{\psi-1} = (b-a) P_m \lambda_1 \tag{2.10b}$$

$$\theta_l l^{\gamma\theta_l - 1}[c_p^{\theta_c} m^{1-\theta_c} h^{\theta_h}]^{\gamma} = \lambda_1 (1-\tau_w) w \tag{2.10c}$$

$$\lambda_2 (1-\psi) B \left[\frac{m}{u}\right]^{\psi} = \lambda_1 (1-\tau_w) w \tag{2.10d}$$

$$\frac{-\dot{\lambda_1}}{\lambda_1} = (1-\tau_k) r - \delta_k - \beta \tag{2.10e}$$

$$\frac{-\dot{\lambda_2}}{\lambda_2} = \left[\frac{\theta_h h^{\gamma\theta_h - 1}[c_p^{\theta_c} m^{1-\theta_c} l^{\theta_l}]^{\gamma}}{\lambda_2}\right] - [\delta_h + \rho(u) + \beta] \tag{2.10f}$$

Equation (2.10a) equates the marginal utility of non-medical consumption with the shadow cost of physical capital. Combing equations (2.10a) and (2.10b) implies that the marginal utility of medical consumption plus the marginal return of health care on health investment is equal to the marginal utility of non-medical consumption weighted by the out-of-pocket cost of medical consumption relative to non-medical consumption. Equations (2.10c) and (2.10d) state that the marginal utility of leisure time and the marginal return of health maintenance time on health investment are equal to the after-tax marginal cost of lost wages.

Equation (2.10e) equates capital gains $-\dot{\lambda_1}/\lambda_1$ with the after-tax rate of return to financial assets minus the depreciation rate of physical capital and the rate of time preference. Finally, equation (2.10f) equates health capital gains $-\dot{\lambda_2}/\lambda_2$ with the marginal utility of health capital minus total depreciation of health capital and the rate of time preference.

The core dynamics are expressed in equations (2.11a)-(2.11d). Substituting equations (2.4a), (2.5b) and (2.6) into equation (2.7) and rearranging terms in the household's budget constraint yields:

$$\dot{k} = (1-g)y - c_p - (1-a)(\nu m^{\nu-1})m - \delta_k k \tag{2.11a}$$

$$\dot{h} = F(m,u) - [\delta_h + \rho(u)]h \tag{2.11b}$$

$$\dot{\lambda_1} = \left[\delta_k + \beta - \alpha(1-\tau_k)Ah^{\eta}\left(\frac{k}{1-u-l}\right)^{\alpha-1}\right]\lambda_1 \tag{2.11c}$$

$$\dot{\lambda_2} = [\delta_h + \rho(u) + \beta]\lambda_2 - \theta_h h^{\gamma\theta_h - 1}[c_p^{\theta_c} m^{1-\theta_c} l^{\theta_l}]^{\gamma} \tag{2.11d}$$

Due to the complexity of the model, the steady-state variables cannot be solved for explicitly. Therefore, I solve for the steady-state numerically. To solve for the steady-state variables I set $\{\dot{k}, \dot{h}, \dot{\lambda_1}, \dot{\lambda_2}\} = 0$ in equations (2.11a)-(2.11d):

$$\tilde{y} = \tilde{c_p} + g\tilde{y} + (1-a)(\nu\tilde{m}^{\nu-1})\tilde{m} + \delta_k\tilde{k} \tag{2.11a$'$}$$

$$B\tilde{m}^{\psi}\tilde{u}^{1-\psi} = [\delta_h + \rho(\tilde{u})]\tilde{h} \tag{2.11b$'$}$$

$$\alpha(1-\tau_k)A\tilde{h}^{\eta}\left(\frac{\tilde{k}}{1-\tilde{u}-\tilde{l}}\right)^{\alpha-1} = \delta_k + \beta \tag{2.11c$'$}$$

$$[\delta_h + \rho(\tilde{u}) + \beta]\tilde{\lambda_2} = \theta_h\tilde{h}^{\gamma\theta_h - 1}[\tilde{c_p}^{\theta_c}\tilde{m}^{1-\theta_c}\tilde{l}^{\theta_l}]^{\gamma} \tag{2.11d$'$}$$

The steady-state conditions described by equations (2.11a′)-(2.11d′) can be interpreted as follows: Equation (2.11a′) implies that steady-state output will be equal to the sum of steady-state private non-medical consumption, government consumption, private medical consumption,[6], and depreciation of physical capital. Equation (2.11b′) states that health investment will equal the total depreciation of health capital in the steady-state. Equation (2.11c′) equates the steady-state after-tax return to physical capital (i.e. the after-tax marginal product of physical capital) to the sum of the physical capital depreciation rate and the rate of time preference. Finally, equation (2.11d′) implies that the steady-state marginal

[6]Note that $\nu\tilde{m}^{\nu-1}$ is the steady-state equilibrium price of medical consumption relative to non-medical consumption.

utility of health capital will be equal to the sum of the total health capital deprecation rate and the rate of time preference, weighted by the steady-state shadow cost of health capital.

Using equations (2.11a′)-(2.11d′), I can solve for the state and co-state variables numerically. Then, using these values for the state and co-state variables I can solve for the numerical steady-state levels for the choice variables.

2.4 Data

The National Income and Product Accounts (NIPA) and the National Health Expenditures Accounts (NHEA) are the two main sources I use in the calibration of the model. NIPA provides estimates of public and private consumption. Unfortunately, NIPA's estimate of personal consumption expenditures includes household purchases of medical goods and services. As a result, I must rely on separate estimates of public and private medical expenditures from the NHEA to construct a final estimate of public and private medical and non-medical consumption.

In the model, I treat medical consumption as the utilization of medical care that is purchased in response to the advent of a specific illness. Therefore, in order to avoid counting other forms of medical expenditures that are not relevant to the current study, such as R&D expenditures, I calibrate aggregate medical consumption to match PHC expenditures instead of national health expenditures. NHEA also breaks down PHC expenditures according to the source of payment, allowing me to obtain estimates of publicly and privately financed medical consumption (m_g and m_p respectively). Non-medical consumption is obtained by subtracting my estimate of medical consumption from total personal consumption expenditures obtained from NIPA.

In addition to using NHEA to construct measures of medical and non-medical consumption, I also utilize it to create estimates of the fraction of total healthcare financed by private health insurance $(1-b)$, public health insurance (a), and out-of-pocket payments from the household $(b-a)$. Additionally, NHEA estimates can be used to create an estimate of total premiums paid. Unfortunately, NHEA does not provide a single variable for total health insurance premiums. Instead, premium payments can be estimated as the sum of the net cost of health insurance and total private health insurance expenditures.[7]

Total output data from NIPA is used to construct estimates of the output shares of medical and non-medical consumption, total premiums, government consumption, and out-of-pocket expenditures. I also utilize NIPA data to estimate the average effective income tax rate following the procedure proposed by Gomme and Rupert (2005). The first step in Gomme and Rupert's procedure is to compute the tax rate on household income, τ_h:

$$\tau_h = \frac{\text{Personal Current Taxes}}{\text{Net Interest} + \text{Proprietors' Income} + \text{Rental Income} + \text{Compensation of Employees}} \tag{2.12}$$

This tax rate is used to calculate the average effective tax rate on labor income, τ_w:

$$\tau_w = \frac{\tau_h(\text{Compensation of Employees}) + \text{Contributions for Social Insurance}}{\text{Compensation of Employees} + \text{Employer Contributions OASDI}} \tag{2.13}$$

where OASDI stands for Old Age, Survivors and Disability Income.

There are several variables and parameters that I employ in calibration that cannot be calibrated from either the NHEA or NIPA. Therefore, I supplement NHEA and NIPA with data from several other sources. First, since NIPA does not have any estimates of the physical capital stock, I have opted to use the physical capital stock estimates from the Penn World Tables 8.1 (PWT) to calibrate the physical capital-output ratio. Additionally, the PWT 8.1 has data on the average annual hours worked per person engaged in the labor force that I use to calibrate labor hours. Second, health maintenance time is computed from

[7] Defined as "the difference between premiums earned by insurers and the claims or losses incurred for which insurers become liable."

the American Time Use Survey (ATUS) as the fraction of the respondent's time devoted to sports and exercise, medical care, health-related care for others, and health-related self care.

The final parameter I calibrate is the endogenous depreciation rate of health capital $\rho(u)$. The calibration of $\rho(u)$ is problematic. The Medical Expenditures Panel Survery (MEPS) has very in-depth information on the specific condition, the type of visit (i.e. inpatient, outpatient, or ER), as well as some detail on what was done during the visit. However, it is difficult to discern how to precisely exploit this information to create calibrate $\rho(u)$. Using conditions to estimate $\rho(u)$ is tenuous. For example, should a condition like hypertension be included? In some cases hypertension is treated solely through an increase in exercise and a change in diet, while in others it is treated with medication. Furthermore, some individuals with hypertension may present with more frequent and more severe angina resulting in greater utilization of medical services. Including hypertensive individuals would overestimate $\rho(u)$, while excluding hypertensive individuals would underestimate $\rho(u)$.

Similarly, using type of visit is imperfect. For example, outpatient care incorporates a wide variety medical services, from diagnostic and preventive medicine (i.e. consultations, MRI and CT scans, vaccinations, follow-ups, etc.) that may not indicate the presence of a condition requiring acute care, to the treatment of specific conditions (i.e. outpatient surgical procedures, chemotherapy, emergency services, etc.) that should be included. In many cases it is not possible to separate the outpatient visits in MEPS that are relevant for estimating $\rho(u)$, from the irrelevant visits.

Alternatively, I have chosen to estimate $\rho(u)$ using total expenditures data provided by MEPS. According to Cohen and Yu (2012), in 2008, 1 percent of the population accounted for nearly 20.2 percent of all healthcare expenditures. Similarly, nearly 50 percent of all expenditures in 2008 were incurred by only 5 percent of the population (with a mean expenditure of $35,829). This indicates that serious medical events will be associated with substantial levels of expenditures. Therefore, it should be possible to define a minimum annual expenditure threshold that can separate individuals who have had an adverse shock to their health from those who have not.

An overnight stay in a hospital is most likely the result of a serious medical event. Therefore, the expenditures incurred during an inpatient stay are indicative of the sort of expenditures that are associated with a major condition. As a result, I define the threshold as the lower bound for expenditures for the top 90 percent of inpatient spenders for each year in the sample. The magnitude of ρ will therefore be equal to the fraction of households with total annual expenditures above the annual threshold. The expenditure threshold for each year in the sample is listed in Table A.1 located in the Appendix.

2.4.1 Parameterization

Table 2.1 below provides a brief description of the model's parameters, the values employed and the source that motivates the selection of that value. The preference parameters, $\{\theta^c, \theta^h, \theta^l\}$, along with the parameters $\{\eta, \mu, \psi, \nu\}$, are chosen in order to calibrate the model to match the output shares of non-medical consumption, medical consumption and the time allocation between labor, leisure and health maintenance. For simplicity, I normalize final goods and health investment productivity (A and B) to one.

Finally, δ_h is motivated by Dalgaard and Strulik (2010). Dalgaard and Strulik define aging as the development of an increasing number of "deficits" (taken from Mitnitski et al. [2002]) which can be thought of as a wide variety of disorders ranging from minor irritations such as declining hearing to major events such as strokes. Dalgaard and Strulik cite two separate studies (Mitnitski et al. [2002] and Rockwood and Mitnitski [2007]) that estimate that the aggregate average accumulation of deficits is 3-4% more deficits per year.

Table 2.1: Chapter 2: Parameters

Parameter	Value	Description [Source]
γ	-1.5	Determines IES of c (IES=0.4); [Ogaki & Reinhart (1998) & Guvenen (2006)]
θ_c	0.965	Preference parameter for non-medical consumption
θ_h	0.1	Preference parameter for health
θ_l	1.75	Preference parameter for leisure time
A	1.0	TFP of final goods production; [Normalized to 1]
α	0.4	Share of income due to capital; [Literature standard]
η	0.05	Productivity parameter for health
δ_k	0.08	Depreciation rate of capital; [Klenow & Rodriguez-Clare (2005)]
$\bar{\rho}$	0.167	Exogenous component of fraction of households w/ health shock; [MEPS]
μ	0.25	Curvature of the ρ wrt u
B	1.0	TFP of health investment; [Normalized to 1]
ψ	0.2	Share of health investment due to healthcare
δ_h	0.04	Depreciation rate of health stock; [Dalgaard & Strulik (2010)]
ν	2.0	Curvature parameter for medical care cost function
τ_w	0.25	Tax rate on labor income; [NIPA]
τ_k	0.15	Tax rate on capital income; [Chatterjee, Guiliano, and Turnovsky (2004)]
g	0.201	Government spending-to-output ratio; [NIPA]
b	0.653	Coinsurance rate; [NHEA]
a	0.445	Public medical subsidy; [NHEA]
$b - a$	0.208	Fraction of medical consumption paid out-of-pocket; [NHEA]

2.4.2 Calibration

The model is calibrated to match the US data contained in Table 2.2 from the period 1996-2013,[8] while Table 2.3 compares the steady-state results from the model with US data. The model predicts a medical expenditures-output ratio that closely matches what is observed in the data, which, given the structure of the model, also pins-down the output ratios for public and private medical consumption and public non-medical consumption. Additionally, the relative price of medical care and the premium-output ratio are extremely close to the levels observed in the data.

Table 2.2: US Data (1996-2013)

Variable	Value	Description; [Source]
k/y^*	3.040	Physical capital-output ratio; NIPA & PWT 8.0
c_p/y	0.550	Private non-medical consumption-output ratio; NIPA & NHEA
c_g/y	0.144	Public non-medical consumption-output ratio; NIPA & NHEA
m/y	0.130	Medical consumption-output ratio; NIPA & NHEA
m_p/y	0.072	Private medical consumption-output ratio; NIPA & NHEA
m_g/y	0.058	Public non-medical consumption-output ratio; NIPA & NHEA
oop/y	0.020	Out-of-pocket medical consumption-output ratio; NIPA & NHEA
Π/y	0.051	Total premiums-output ratio; NIPA & NHEA
n	0.294	Average annual hours worked by persons engaged; PWT 8.0
u	0.024	Health maintenance time; ATUS
l	0.682	Leisure time ($l = 1 - n - u$)
a	0.445	Public-total medical consumption ratio; NHEA
g	0.201	Government expenditures-output ratio; NIPA
τ_w	0.250	Average effective tax rate on labor income; NIPA
τ_k	0.150	Average effective tax rate on capital income
ρ	0.167	Fraction of households with acute care; MEPS

* Data is from 1996-2011, since 2011 is most recently available data for the capital stock.

Table 2.3: Model vs. Data

	k/y	c_p/y	c_g/y	m/y	m_p/y	m_g/y	n	l	u	Π/y
Data	3.040	0.550	0.144	0.130	0.072	0.058	0.294	0.682	0.024	0.051
Model	2.833	0.501	0.144	0.129	0.072	0.057	0.306	0.668	0.026	0.045

[8] 1996 is the first year MEPS data is available.

As a result of the absence of government investment, the model slightly under predicts the physical capital-output and non-medical consumption-output ratios. Without government investment, household savings will be the sole source of investment in physical capital. Consequently, in order to accumulate enough physical capital to match the observed physical capital-output ratio the representative household will have to devote a greater fraction of total output to investment than occurs in the US. Therefore, the non-medical consumption-output and physical capital-output ratios predicted by the model will be slightly below their observed levels. Finally, the predicted household time allocation compares favorably to the data. Health maintenance time matches the fraction of time observed in the data. The model marginally under predicts the fraction of household time devoted to labor.

2.5 Long-Run Effects

In this section I analyze the aggregate steady-state response to the five scenarios examined in the preceding section. In particular I focus on the subsequent changes to medical and non-medical consumption, leisure time, and the agent's health stock as these variables directly impact aggregate social welfare. Table 2.4 presents the steady-state response of the model for each scenario.

Table 2.4: Percent Change of Steady-State Variables and Welfare

	y	k	h	c_p	c_g	m^{**}	n	l	u	Π^{***}	Ω
A	1.686	1.686	0.167	1.686	1.686	0.840	0.000	0.000	0.000	1.686	1.993
B	0.084	0.084	1.008	0.084	0.084	0.042	0.000	0.000	0.000	0.084	0.213
$\bar{\rho}$	-0.060	-0.060	-0.701	-0.066	-0.075	-0.012	-0.002	-0.004	0.126	-0.024	-0.169
a	0.023	0.023	0.200	-0.148	-1.191	1.012	0.006	-0.003	-0.003	2.035	-0.153
b	-0.036	-0.036	-0.269	0.347	1.034	-1.363	-0.013	0.006	0.006	-4.539	0.423

* All values represent the percent change from the steady-state.
** Total medical expenditures ($P_m m$) change by 1.686, 0.084, -0.024, 2.035, -2.708 percent.
*** Total premium payments to the health insurer.

2.5.1 Productivity Increases

This subsection compares the long-run effect of a one percent rise in final goods productivity to the long-run effect of a one percent increase in medical investment productivity.

Final Goods Productivity

Increases to final goods productivity generate the largest increase in social welfare of the five scenarios considered, with a one percent rise in productivity resulting in an increase in aggregate welfare of 1.993 percent. This result is driven by the direct effect that an increase of final goods productivity has on output. In this case, a one percent increase in productivity immediately results in a one percent rise in output. This allows the household to begin accumulating more physical capital, generating a secondary increase in output, so that a one percent increase in productivity will result in a 1.686 percent rise in steady-state output.

Changes to final goods productivity do not effect the long-run medical and non-medical consumption-output ratios or time allocations. However, the rise in total output does allow the household to increase total consumption of each good, improving aggregate welfare. Also, it is important to note that only a portion of the growth in medical expenditures can be explained by the resulting increase in the steady-state consumption of medical services. The remainder of the rise in medical expenditures is explained by a rise in the relative price of medical care. Therefore, the model not only predicts that medical consumption will rise along with productivity, as in Hall and Jones (2007), it also predicts that medical consumption will become more costly relative to non-medical consumption.

Medical Investment Productivity

A rise in medical productivity is similar to an increase in final goods productivity in that there is no change in household time use, as well as proportional increases to physical capital, expenditures, and insurance premiums relative to output. However, increases in health investment productivity do not have an immediate and direct impact on output. Instead, output will rise only when the health stock begins accumulating. In turn, as output increases, the household can begin to accumulate additional physical capital. However, since output is subject to diminishing returns to health and physical capital, the rise in steady-state output will be significantly less than occurs with a comparable increase in final goods productivity. As a result, medical and non-medical consumption only rise by 0.084 percent, making the subsequent increase in welfare over 9 times lower than occurs in response to an increase in final goods productivity.

The neoclassical framework underpinning this model implies that there will be no change in the steady-state savings rate in response to a productivity shock. As a result, the physical capital, medical consumption, and non-medical consumption to output ratios are unaffected in the long-run. Note that this does not necessarily conflict with Hall and Jones (2007) and Newhouse (1992), who found that persistent income growth and medical advancement will cause the medical consumption-output ratio to rise over time, since I am considering only one-time permanent shocks to either final goods or health investment productivity.

2.5.2 Endogenous Depreciation Rate of Health

The exogenous component of health capital depreciation ($\bar{\rho}$) is intended to represent any factor outside of the household's control that determines the size of the depreciation rate of health capital, such as its genetic predisposition to illness, demographics, the severity of infectious diseases, etc. A one percent rise in $\bar{\rho}$ causes health capital to depreciate at a quicker rate, resulting in a decline in the household's health stock. As the health stock falls, the household becomes less productive. In response, the household will reduce its consumption of both medical and non-medical goods, causing welfare to decrease by 0.169 percent.

The decline in medical expenditures that occurs in response to an increase in the depreciation rate of health is somewhat surprising. To explain this counter-intuitive prediction consider that as the depreciation rate rises, the household's health capital will decline, resulting in a decrease in output and household income. Consequently, the household cannot afford as many medical services. However, total medical expenditures decreases by slightly less than the output (0.024 versus 0.06 percent), so that the medical consumption-output ratio rises slightly.

2.5.3 Public Insurance Subsidy

Changes to the public insurance subsidy rate are intended to mimic a change in the fraction of aggregate medical consumption funded by the government. This could be related to a change in enrollment in Medicare or Medicaid, or any modification in how public insurance pays for service such as changes to Medicare Part B coinsurance rates, or Medicare and Medicaid DRG payment weights, etc.

Intuitively, a one percent increase in the public subsidy rate reduces the cost of medical consumption, prompting the household to increase steady-state medical services by 1.012 percent, raising medical expenditures by 2.035 percent. In all the fraction of total output devoted to medical consumption will increase by 2.012 percent.

Since a greater percentage of output is being devoted to medical consumption and the physical capital-output ratio is unaffected, the non-medical consumption-output ratio will fall by 0.403 percent. In fact, the increase in medical expenditures is large enough to not only cause c/y to fall, but aggregate steady-state private non-medical consumption will fall by 0.148 percent. This minor decline in private non-medical consumption is significant enough to reduce welfare by 0.153 percent despite the fact that leisure time is relatively unchanged and medical consumption and the health stock both rise.

2.5.4 Private Insurance Coinsurance Rate

Raising the private coinsurance rate by one percent has the opposite effect on the economy as a one percent increase to the public subsidy rate. In this scenario, private health insurance policies have become less generous, raising the fraction of medical care financed out-of-pocket by the household. Since the household is paying for a larger fraction of health care out-of-pocket, it will decrease its steady-state medical consumption in favor of greater non-medical consumption. Declining medical consumption causes the household's health stock to fall by 0.269 percent, reducing total output slightly. However, the increase in private non-medical consumption is significant enough that welfare increases by 0.423 percent even though there is a considerable decline to both medical consumption and health.

In response to the increase in the coinsurance rate, steady-state medical services decline by 1.363 percent, causing aggregate medical expenditures to fall by 2.708 percent. In each of the other scenarios total premiums rose or fell in proportion with medical expenditures. However, in this case total premiums fall by significantly more than medical expenditures. This is because a one percent increase in b is equivalent to a 1.882 percent reduction in the fraction of health care financed by the insurer. This large reduction in total premium payments raises the wage rate by 0.341 percent, contributing to a 0.176 percent rise in total household income. Therefore, the connection between private health insurance and the labor market implies that changes to private health insurance have a much greater impact on the economy than changes to public insurance.

2.5.5 Crowding Out

Before turning to the transition dynamics, I examine the claims that medical expenditures growth threatens to crowd out non-medical consumption, discretionary government expenditures, and investment. According to my analysis, a one percent increase of $\bar{\rho}$ or the public medical subsidy will cause the medical consumption-output ratio to rise (0.037 percent and 2.012 percent respectively). In each case there is a small decline in private non-medical consumption (0.005 percent and 0.177 percent) and a much larger decline in public non-medical consumption (0.015 percent and 1.213 percent). At the same time there is no change in the physical capital-output ratio.

Therefore, the model rejects the hypothesis that the expansion of the health care sector will diminish investment. Conversely, the model supports claims that non-medical consumption will be crowded out. In particular, assuming that the capital and labor tax rates are fixed, public non-medical consumption appears to be more severely affected than private non-medical consumption. In the current framework I assume that households do not receive utility from public non-medical consumption. Consequently, the negative impact of reduced public expenditures on aggregate welfare may be more substantial than suggested here.

2.6 Transition Dynamics

In this section I analyze the transition dynamics for a one percent increase in each of the following; final goods productivity, medical sector productivity, the exogenous component of ρ, the private insurance coinsurance rate and the public medical subsidy rate. The transition paths of (a) output, (b) leisure time, (c) health maintenance time, (d) physical capital, (e) private non-medical consumption, (f) medical services, (g) physical capital-output, (h) private non-medical consumption-output, and (i) medical consumption-output for each of these five scenarios are contained in the Appendix.

2.6.1 Productivity Increases

In the model I assume that the productivity of final goods and health investment may differ. Additionally, I assume that these two productivity levels are uncorrelated so that an increase in final goods productivity will not cause the productivity of health investment to rise and vice-versa. Consequently, in the following analysis I consider the response of the model to a rise in each type of productivity separately.

Final Goods Productivity

Figure A.1 presents the transition dynamics for a one percent rise in final goods productivity. The increase in productivity has an instantaneous impact on the wage and interest rates, triggering an immediate increase in labor time and physical capital investment. This causes leisure and health maintenance time to fall initially. The productivity increase combined with the increase in labor hours causes output to immediately increase by more than one percent. As physical capital begins to accumulate, total output continues to rise at a diminishing rate, returning the physical capital-output ratio to its initial level, so that the interest and wage rates are unaltered in the long-run. Leisure and health maintenance time fall back to their previous values as the wage rate returns to its original value. Taking advantage of the instantaneous jump in total output, the household increases both medical and non-medical consumption. Consumption of both goods will continue to rise along with total output until it finally settles on its new steady-state value.

Health Investment Productivity

A one percent rise in medical sector productivity makes health investment relatively more attractive, inducing substantial and instantaneous jumps in medical services consumption and health maintenance time. The sudden jump in medical consumption raises the marginal utility of leisure and non-medical consumption, stimulating an immediate increase in non-medical consumption and leisure time. However, since the health stock is fixed initially, the decline in labor time causes total output to fall at first. The temporary decline in output combined with the increase in household expenditures implies that investment will fall in the short run, causing physical capital to decline temporarily.

The rise in medical productivity and the resulting increase in medical expenditures will cause the health stock to accumulate very quickly, raising the household's productivity, leading to an increase of both total output and the wage rate. In response to rising wage rates, the household increases its labor time, causing leisure and health maintenance time to fall back to their previous levels. Additionally, the initial decline in the physical capital stock raises the marginal product of capital (i.e. the interest rate), stimulating increased savings. As a result, the physical capital stock begins to rise again, while consumption of both goods falls temporarily. In the long-run the interest rate will be unaffected and the physical capital stock, medical consumption, and non-medical consumption all rise in proportion with total output.

2.6.2 Endogenous Depreciation Rate of Health

Initially, the household responds to an increase in the magnitude of $\bar{\rho}$ by increasing labor time and savings in anticipation of the financial burden associated with an increase in the severity of illnesses and accidents. Therefore, as panels (a)-(d) in Figure A.3 demonstrate, household consumption and non-labor time all decline at first. Additional labor time and savings leads to a rise of both physical capital and output. Therefore, after the initial decline in medical and non-medical consumption, expenditures will begin to rise again.

However, since the household's health is depreciating at a faster rate, its health stock will begin to decline. In response, the household will devote more time to health maintenance in order to mitigate some of the impact of the increased depreciation rate of its health stock. The household's diminished health stock and declining labor time causes total output to fall.

Medical and non-medical consumption will begin falling again as household income declines. Despite the reduction in household expenditures, the decline in total output results in a decrease in the steady-state physical capital stock.

2.6.3 Public Insurance Subsidy

Since the household does not internalize the effect its medical consumption has on premiums, it will perceive a one percent increase in the public insurance subsidy as a permanent reduction in the cost of health care. As a result, the household will devote a greater fraction of its income to health investment, substituting away from non-medical consumption. Similarly, health maintenance time rises initially. However, in the long-run the household will increase labor time, decreasing both leisure and health maintenance time.

Medical consumption, leisure time and health maintenance time all increase considerably at first, while non-medical consumption and output decrease. Both declining output and increasing total expenditures cause investment in physical capital to fall temporarily. However, as labor time climbs to its new steady-state level (only 0.006 percent above its initial value) and the health stock begins to accumulate, total output will rise above its pre-change level. As output begins to grow, the household is able to accumulate additional physical capital. Medical consumption briefly over-shoots its final steady-state value, eventually falling in response to the decline in total output and settling to its new steady-state level above its pre-shock steady-state level. Similarly, non-medical consumption slightly under-shoots its final steady-state level (which is below its initial steady-state level), increasing along with the growth of total output that results from the rise of the household's health stock.

2.6.4 Private Insurance Coinsurance Rate

A one percent increase of the private coinsurance rate raises the out-of-pocket cost and therefore has the opposite effect of what was described in the Section 2.5.3. Consequently, the household will opt for greater non-medical consumption, leisure time, and health maintenance time, reducing medical consumption. Medical services and health maintenance time all temporarily decline, leading to a brief increase in output. Nevertheless, the household's health stock ultimately falls by 0.269 percent, causing total output and physical capital to fall below their initial levels.

2.7 Conclusions

Over the past several decades the growth of medical expenditures in the US has significantly outpaced the growth of GDP, leading to concern that household and government budgets will become increasingly constrained. In response, health economists have sought to identify the various factors in the economy driving the rapid expansion of the medical sector. This line of research successfully identified several factors driving the growth of this sector, including rising income levels, the introduction of new medical technologies, increasing access to and generosity of health insurance, aging of the population, and over-insurance. However, there has yet to be a systematic investigation of the aggregate consequences of changes to the determinants driving the growth of the health care sector identified by health economists. As a result, it is unclear whether or not the implementation of cost containment policies is as urgent as some assert.

Therefore, in this chapter I extend the standard Neoclassical growth model to include health capital accumulation, public and private health insurance and a health care market in order to analyze the aggregate welfare implications of changes to the factors driving the rapid growth of the health care sector. The household obtains private health insurance via an employer-provided benefit, while public insurance is treated as a subsidy equal to the fraction of total medical expenditures financed by the government. Utilizing this model, I investigate the aggregate response to changes in the economy intended to imitate the determinants of the expansion of the health care sector identified above.

A one percent rise in final goods productivity has a considerable and direct impact on income, allowing the household to significantly increase both medical and non-medical consumption, with the former having a positive impact on the household's health stock. Consequently, there is a substantial increase in aggregate welfare (1.993 percent). In comparison, the introduction of a new medical technology that raises health investment productivity has a much smaller impact on welfare (0.213 percent), as changes to health investment productivity directly effect the household's health stock, which in turn has only a minor positive effect on total output. As a result, the subsequent increase in consumption that results from rising household income is significantly smaller than occurs with changes to final goods productivity.

Not surprisingly an exogenous increase in the rate of depreciation of health has a negative effect on welfare (-0.169 percent). As illnesses become more severe, the household will increase the time it devotes to health maintenance. Since the household is spending less time in the labor market and its health stock is declining, total output will fall. Consequently, the household will not be able to purchase as many medical services. However, despite the fact that the household is consuming fewer medical services, a larger portion of total output will be devoted to medical expenditures, reducing total non-medical consumption.

Interestingly, the model predicts that a reduction in the fraction of health care financed out-of-pocket (i.e. $b-a$) will lead to a decrease in total welfare. Though this may appear to be counterintuitive at first, it supports claims that health insurance policies are too generous in the US, generating an incentive for households to consume too many medical services relative to non-medical consumption. Decreasing the out-of-pocket cost to the household encourages further substitution of non-medical consumption in favor of increased health investment, thereby reducing total welfare. Conversely, decreasing the generosity of private health insurance policies has a positive impact on welfare as it provides an incentive for the household to substitute medical consumption in favor of non-medical consumption.

In addition, reducing private health insurance generosity (as opposed to public health insurance generosity) has a much greater effect on health insurance premiums. Consequently, reducing private health insurance generosity will increase labor income by more than reducing public health insurance generosity, allowing the household to increase non-medical consumption by more, without sacrificing too much medical consumption. This is potentially very important with respect to health care policy if households in the US are in fact over-insured. If this is the case, then policymakers will want to increase out-of-pocket expenditures by making private health insurance less generous or curtailing public health insurance expenditures. However, the model suggests that policies that target private health insurance generosity, such as removing the tax-exempt status of health insurance benefits, eliminating employer-based private health insurance, promoting health savings accounts, or removing some of the minimum acceptable coverage restrictions on insurance plans may be more effective than simply attempting to limit public insurance expenditures.

Finally, since the steady-state physical capital-output ratio is unaffected in all of the scenarios I consider, I reject the hypothesis that the increase of the income share of medical consumption over time will crowd out private investment. On the other hand, both public and private non-medical consumption decline relative to output when the medical consumption-output ratio rises. However, the decline of the private and public non-medical consumption-output ratios is small enough relative to the rise in the medical consumption-output ratio that the negative impact on aggregate welfare is minimal.

Chapter 3

The Macroeconomic Consequences of Health Care Reform and Fiscal Policy

3.1 Introduction

The persistent rise of medical expenditures relative to output that has occurred throughout the past half century has thrust considerations of the aggregate role of health and health care to the forefront of macroeconomic research. Recent aggregate models of health and health insurance have largely concentrated on explaining how changing macroeconomic conditions have led to the rise in medical expenditures and longevity. Others have focused on conducting welfare analyses of health care reform. This new line of research has provided valuable insight into the aggregate steady-state consequences of medical expenditure growth and health care reform. Unfortunately, in most cases, economic growth has been treated as exogenous, limiting our understanding of how health care reform will impact growth in the long-run. Therefore, utilizing a novel continuous time OLG model with exogenous mortality, I examine how health care reform and changes to fiscal policy will affect aggregate consumption, savings, labor supply, and, subsequently, economic growth.

Concerns that the expansion of the health care sector will result in adverse aggregate consequences have existed for several decades. Such concerns have some merit. Between 1960 and 2013, the medical consumption share of GDP grew by 2.3 percent on average annually, increasing by a factor of more than 3.4. Some economists, such as Auerbach, Gokhale, and Kotlifkoff (1992) and Hsiao and Heller (2007), have suggested that if medical consumption continues to rise relative to output, then public and private non-medical consumption and investment will be crowded out.

Numerous microeconomic studies have identified and estimated the welfare losses arising from various market failures that exist in the health care and health insurance markets.[1] Consequently, the continued expansion of medical expenditures not only threatens to crowd out consumption and investment, it also magnifies the welfare losses associated with the health care sector. Combined, these two factors have led many economists and policymakers to conclude that aggregate welfare and productivity growth will be adversely affected by further growth of medical expenditures relative to output.

Curiously, macroeconomic investigations of rising health care consumption were largely non-existent prior to Hall and Jones (2007), despite the potential aggregate implications. Hall and Jones (2007) developed an aggregate OLG model with endogenous mortality to investigate the relationship between income growth and the medical expenditure-output ratio. Hall and Jones contend that, as income levels rise, total consumption of non-medical goods and services will increase, reducing the marginal utility of consumption. At the same time, the marginal utility of health investment remains constant so that the marginal utility of health investment is rising relative to the marginal utility of consumption. Thus, the optimal income share of health investment increases alongside rising income levels. Using a quantitative analysis based on their model, Hall and Jones project that the optimal health

[1] e.g. Over-insurance from asymmetry in health insurance markets (Arrow (1963), Feldstein [1973], Pauly [1974], Rothschild and Stiglitz [1976], and Feldman and Dowd [1991]), the tax-exempt status of health insurance benefits (Pauly [1986]), and supplier-induced demand (McGuire [2000]).

share of spending relative to output will continue to rise and could exceed 30 percent by the middle of the century.

Suen (2013) extends the Hall and Jones model to include public and private health insurance and medical technology growth. He concludes that technological advancements in the health care sector and income growth explain all of the growth of medical expenditures and more than 60 percent of the rise in life expectancy at age 25 that occurred in the US from 1950-2001. Similarly, Zhao (2014) also extends Hall and Jones' model, including public and private health insurance and Social Security. He finds that the expansion of Social Security accounts for over a third of the rise in health care spending from 1950-2000, as Social Security transfers resources from the young to the old who have a greater marginal propensity to consume health care. Ultimately, Zhao concludes that Social Security expansion and the subsequent rise in the health share of income are welfare reducing.

Thus, from Hall and Jones (2007) and Suen (2013) we have strong evidence supporting the theoretical mechanism through which income growth produces medical expenditure growth. In contrast, it is possible that changes to aggregate medical consumption will impact aggregate savings and the labor income tax rate, which in turn affect the growth rate of output. Consequently, health care reform may potentially have an impact on the balanced growth path through its effect on medical consumption and savings. Additionally, as Zhao (2014) demonstrates, non-medical fiscal policy changes, such as an expansion of Social Security, can influence medical consumption, potentially altering the effect that health care spending has economic growth and welfare.

Several other studies have examined the aggregate consequences of health care reform within a general equilibrium framework. Feng (2009) develops a stochastic OLG equilibrium model with heterogeneous agents to analyze the effect of various health care reforms on the number of uninsured, labor supply, and welfare. Similarly, Chivers, Feng, and Villamil (2014) utilize a general equilibrium model to study the effect of mandated health benefits on firm size, productivity, GDP, earnings, and welfare. However, both of these studies consider the steady-state welfare effects in an exogenous growth setting and therefore are unable to fully consider the long-run growth and welfare consequences of the reforms they investigate.

In this chapter I utilize a continuous time version of the Blanchard (1985) and Weil (1989) OLG model with exogenous mortality and endogenous labor supply. The survival function I employ was developed by Boucekkine et al. (2002), and is utilized in Bruce and Turnovsky (2013). I assume that there are two forms of consumption; medical and non-medical. Medical consumption is subsidized at any age by both private health insurance (financed by a premium) and public health insurance (financed by capital and labor income tax revenue). In addition to providing health insurance, the government also produces a government consumption good and public infrastructure investment.[2]

The production technology is a hybrid of the Romer (1986) production function and the Barro (1990) government infrastructure production function. This production technology is also employed by Bruce and Turnovsky (2013) and results in endogenous growth of output. After calibrating the model to match US data from 2006 to 2013, I investigate the response of the balanced growth rate and aggregate welfare to five separate policy scenarios.[3] With only one exception (i.e. increases to public infrastructure investment), both aggregate welfare and the growth rate will decline.

The rest of the chapter is laid out as follows. Section 3.2 briefly discusses the recent health care reforms that motivate the growth rate and welfare analysis contained in Section 3.6. In Section 3.3 I present the household's problem when mortality is exogenous. Section

[2]The interaction between public infrastructure spending and private physical capital generates a productivity externality that results in endogenous growth. The government may be forced to cut discretionary non-medical expenditures as public medical expenditures rise over time. Separating government spending by consumption and investment allows me to evaluate the different effect on economic growth and aggregate welfare that cuts to these two distinct forms of government spending may have in the long-run.

[3]i.e. Increases to 1) the share of privately-financed health care, 2) the share of publicly-financed health care, 3) the rate of infrastructure investment, 4) the share of government consumption to output, and 5) the Medicare eligibility age.

3.4 describes the aggregation process and details the equilibrium in the final goods and health insurance markets. Additionally, Section 3.4 also derives the government's budget constraint and solves for the equilibrium growth rate. Section 3.5 explains the calibration of the benchmark model. In Section 3.6, I evaluate the response of the model to several policy scenarios. Then, in the following chapter, I relax the exogenous mortality assumption and assume that the household's survival probability is endogenously determined by its current medical consumption and age, and I compare the new results with those from the exogenous mortality model. Finally, at the end of Chapter 4, I provide my conclusions from both versions of the OLG model.

3.2 Health Care Reform and Fiscal Policy

Several recent reforms, such as Medicare Part D or the individual mandate and the expansion of Medicaid introduced in the ACA, have significantly altered the health insurance landscape in the US. Prior to the implementation of Medicare Part D in 2006, the government consistently financed between 35 percent and 36.5 percent of medical expenditures.[4] Following the introduction of Medicare Part D, the percentage of government-financed medical expenditures rose steadily, reaching a high of approximately 41.5 percent in 2012.

Medicare expenditures are expected to increase even more as the baby boom generation reaches retirement age, resulting in a substantial increase in the fraction of the population that is eligible for Medicare. According to census data, in 2010, a year before the first baby boomers became eligible for Medicare, approximately 13 percent of the population was above 65 years old. By 2029, when the final baby boomers turn 65, over 20 percent of the population is expected to be over 65. Consequently, the CBO (2015) projects that gross

[4]Data is from MEPS for the period 2001-2012. Medical expenditures are defined as the individual's total expenditures resulting from any inpatient, outpatient, and/or ER stays during the past year. Total expenditures are divided according to the source of payment.

Medicare expenditures will rise from 3.5 percent of GDP in 2015 to 6.3 percent of GDP in 2040, despite the Medicare cost containment policies included in the ACA.

Medicaid and CHIP outlays are also expected to rise over the next decade, due in part to the new policies introduced in the ACA. According to Centers for Medicare and Medicaid Services (2015), between the initial open enrollment period in October 2013 and February 2015, over 10.75 million new individuals were enrolled in either Medicaid or CHIP. The Centers for Medicare and Medicaid Services attributes this rise in enrollment to the increased enrollment that has occurred in states that adopted the ACA's Medicaid expansion, as well as the increased enrollment of individuals who were eligible for either program but not enrolled prior to the individual mandate.

While the share of publicly-financed health care was rising throughout this period, the share of medical expenditures financed by private health insurers was declining in importance, falling from nearly 54 percent of expenditures in 2001 to just under 43 percent in 2012. However, this downward trend may be slowed or even reversed following the implementation of the individual mandate as more households enroll in private insurance plans. In Section 3.6.1, I evaluate the effect of a hypothetical reform that increases enrollment in private health insurance plans that corresponds to a one percent increase in the private health insurance share of medical expenditures. Similarly, in Section 3.6.2 I assume that there is a hypothetical reform that raises public health insurance enrollment, resulting in a one percent rise in the public insurance share of medical expenditures.

Numerous economists (e.g. Auerbach, Gokhale, and Kotlifkoff [1992] and Hsiao and Heller [2007]) anticipate that the aforementioned rise in Medicare expenditures over the next several decades will increasingly constrain government budgets, forcing federal and state governments to raise taxes, cut spending in other areas, or some combination of the two. Therefore, in Sections 3.6.3 and 3.5.4 I analyze how changes to public non-medical consumption and investment impact public medical expenditures, economic growth, and welfare. Alternatively, in order to avoid the adverse effects associated with spending cuts and tax hikes, the government could raise the Medicare eligibility age from 65 to 67. In theory, this policy would diminish some of the cost of health care to the government by delaying Medicare enrollment by two years, reducing the average number of years each person is enrolled in the program. However, as the CBO (2013) notes, the effect of increasing the Medicare eligibility age on public medical expenditures may be offset to a degree by increases to federal health insurance premium subsidies and Medicaid payouts to individuals who would have been covered by Medicare before the change to the eligibility age. Thus, there is some uncertainty over the aggregate consequences of this policy change.

3.3 Households

In this section, I describe the optimal lifetime consumption-saving and labor-leisure plan of a household with an exogenously determined, finite lifetime. The economy is composed of a continuum of identical households belonging to distinct cohorts. Each cohort is designated by the calendar time t when the cohort enters the economy (assumed to be age 20). Let $S(z)$ be the survival function for a household at age z

$$S(z) = \frac{e^{\rho\omega} - e^{\rho z}}{e^{\rho\omega} - 1}, \quad 0 < \rho < 1 \tag{3.1}$$

where ρ is the health investment productivity parameter and ω is the maximum attainable age of the household. $S(z)$ is a stylized version of the Gompertz survival function that was developed by Boucekkine et al. (2002). In the calibration exercise, ρ is set to match the life expectancies of households at ages 20 and 65.

Equation (3.1) implies that the survival probability is independent of calendar time, depending solely on the household's current age. Furthermore, as can be seen from equation

(3.1), for $0 < z < \omega$, $S'(z) < 0$, so that the probability of surviving declines with age. Similarly, for $z \geq \omega$, $S(z) = 0$, implying that all households will be deceased after age ω. Finally, assume that the probability of surviving to age z, conditional on having survived to age x is equivalent to $S(z)/S(x)$.

3.3.1 Utility-Maximization and First-Order Conditions

Let the current time be t and a household's current age be $z < \ell$, where ℓ is the age that all households will retire (i.e. $l_t(z) = 1$ for all $z \geq \ell$). The household's instantaneous utility function takes the following iso-elastic functional form:

$$u[c_t(z), m_t(z), l_t(z)] = \frac{[c_t(z)^{\theta_c} m_t(z)^{\theta_m} l_t(z)^{\theta_l}]^\gamma}{\gamma}, \tag{3.2a}$$

where $-\infty < \gamma < 1$, $\theta_c + \theta_m + \theta_l = 1$, $l_t(z)$ is leisure time, and $m_t(z)$ and $c_t(z)$ are medical and non-medical consumption respectively. Note that the inter-temporal elasticity of substitution is determined by γ.[5]

Since $l_t(z) = 1$ in retirement, the household's instantaneous utility at time t and age $z \geq \ell$ will be:

$$u[c_t(z), m_t(z), l_t(z)] = \frac{[c_t(z)^{\theta_c} m_t(z)^{\theta_m}]^\gamma}{\gamma}. \tag{3.2b}$$

The household will maximize expected remaining lifetime utility as follows:

$$u_t(x) = \int_x^\omega \frac{S(z)}{S(x)} e^{-\beta(z-x)} u[c_{t+z-x}(z), m_{t+z-x}(z), l_{t+z-x}(z)] dz \tag{3.3}$$

subject to the instantaneous, or flow budget constraint

$$a_t'(z) = i_t(z) a_t(z) + w_t(1 - \tau_w)(1 - l_t(z)) - p_t - c_t(z) - \kappa(z) m_t(z), \tag{3.4}$$

[5] $IES = 1/[1-\gamma]$

where β is the rate of time preference, $i_t(z)$ is the return to financial wealth, $a_t(z)$ is financial wealth,[6] w_t is the wage rate, τ_w is th income tax rate, p_t is the premium rate paid by working households, and $\kappa(z)$ is the fraction of the household's medical expenditures that is financed out-of-pocket. I assume that $\kappa(z)$ is a function of the household's current age as follows:

$$\kappa(z) = 1 - \kappa_p(z) - \kappa_g(z), \tag{3.5}$$

where $\kappa_p(z)$ and $\kappa_g(z)$ are the private and government health insurance shares of total medical expenditures respectively, which I assume vary with age.

Figure 3.1, plots the medical expenditure shares by age (i.e. $\kappa_p(z)$, $\kappa_g(z)$, and $\kappa(z)$).[7]

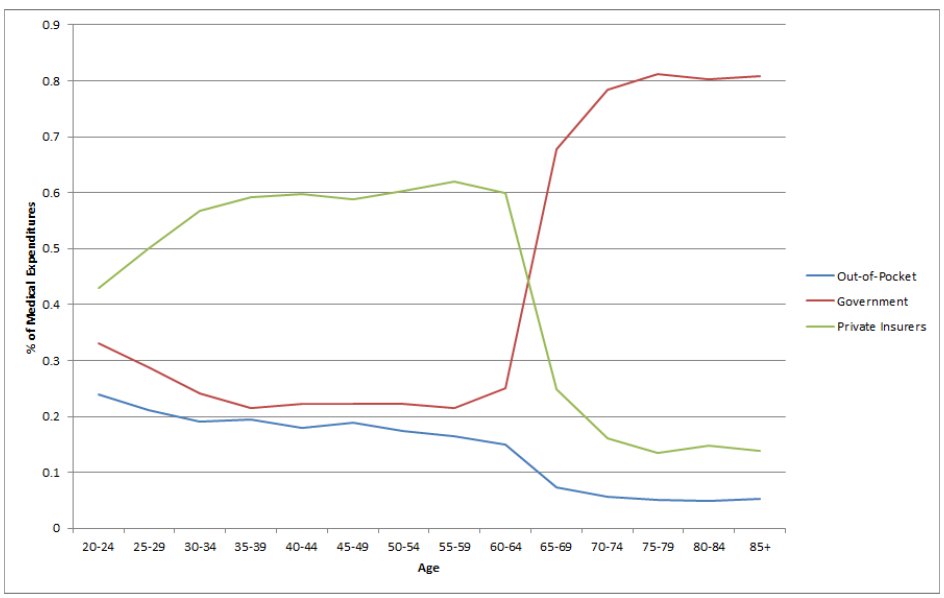


Figure 3.1: Percentage of Medical Expenditures by Source of Payment (by Age)

[6]The household fully invests its financial wealth in physical capital.

[7]The data is obtained from MEPS for the sample period 2006-2012, for individuals aged 20 and older. Total medical expenditures are comprised of the total expenditures that arise from outpatient, inpatient, and emergency room stays of individuals. After applying sample weights, I divide these expenditures according to the source of payment.

For individuals under age 65, private health insurers are the primary source of payment, accounting for an average of 57.3 percent of all expenditures (the government is the next highest, accounting for 24.2 percent). However, once individuals become eligible for Medicare, the private health insurance share drops to 17.5 percent, and the government becomes the primary source of payment (76.6 percent). To account for the sudden rise of the public medical expenditure share that occurs at age 65 (and the corresponding fall in the private health insurance share), I assume that there is a discrete jump/fall of $\kappa_g(z)/\kappa_p(z)$ that occurs when the household becomes eligible for Medicare at age zm.

The present value Hamiltonian that characterizes the agents' objective function will be

$$\begin{aligned}\mathcal{L}_t(z) =& \frac{S(z)}{S(x)} e^{-\beta(z-x)} \{ u[c_t(z), m_t(z), l_t(z)] \\ & + \lambda_t(z)[i_t(z)a_t(z) + w_t(1-\tau_w)(1-l_t(z)) - p_t - c_t(z) - \kappa(z)m_t(z)] \} . \end{aligned} \tag{3.6}$$

The resulting first order conditions are

$$\theta_c c_t(z)^{\gamma\theta_c - 1}[m_t(z)^{\theta_m} l_t(z)^{\theta_l}]^\gamma = \lambda_t(z), \tag{3.7a}$$

$$\theta_m m_t(z)^{\gamma\theta_m - 1}[c_t(z)^{\theta_c} l_t(z)^{\theta_l}]^\gamma = \lambda_t(z)\kappa(z), \tag{3.7b}$$

$$\theta_l l_t(z)^{\gamma\theta_l - 1}[c_t(z)^{\theta_c} m_t(z)^{\theta_m}]^\gamma = \lambda_t(z) w_t(1-\tau_w), \tag{3.7c}$$

$$i_t(z) = \beta - \frac{\lambda_t'(z)}{\lambda_t(z)} - \frac{S'(z)}{S(z)}, \tag{3.7d}$$

where $\lambda_t(z)$ is the shadow value of financial wealth at time t and age z. Equation (3.7a) states that the marginal utility of non-medical consumption will be equal to the household's shadow value of financial wealth. Similarly, (3.7b) equates the marginal utility of medical consumption to the shadow value of financial wealth weighted by the fraction of medical care financed out-of-pocket by the household at age z. Equation (3.7c) sets the marginal utility of leisure time equal to the marginal cost of lost wages resulting from increased leisure time. Note that equation (3.7c) does not apply for ages $z \geq \ell$ since leisure time becomes fixed at one. Finally, (3.7d) sets the rate of return to financial assets equal to the rate of time preference minus capital gains, $\lambda_t'(z)/\lambda_t(z)$, and the mortality hazard rate, $S'(z)/S(z)$.

Following Blanchard (1985), I assume that there are actuarially fair annuities paid to agents in order for the right to inherit their financial wealth upon death. The annuity premium for age z agents will be equal to the mortality hazard rate at age z, $-S'(z)/S(z)$. These annuities ensure that the financial wealth of dying agents is fully recycled to surviving agents. The rate of return on financial wealth will be equal to the after-tax risk-free rate of return to physical capital r plus the annuity premiums paid to the agent. Therefore, $i_t(z) = (1-\tau_k)r - S'(z)/S(z)$, where τ_k is the tax rate on capital income. Consequently, I can claim that the discount factor to a household at age x of a flow at age z is

$$R(z,x) = \frac{S(z)}{S(x)} e^{-(1-\tau_k)r(z-x)}, \tag{3.8}$$

so that

$$\frac{-R'(z,x)}{R(z,x)} = (1-\tau_k)r - \frac{S'(z)}{S(z)} = i_t(z). \tag{3.8$'$}$$

Substituting $i_t(z)$ from (3.8$'$) into (3.7d) yields

$$-\frac{\lambda_t'(z)}{\lambda_t(z)} = (1-\tau_k)r - \beta. \tag{3.7d$'$}$$

Finally, by definition the transversality condition for financial wealth for households at age ω is

$$R(\omega, x)a_t(\omega) = 0. \tag{3.9}$$

3.3.2 Optimal Consumption and Time Plans

The optimal consumption-savings and time use plans for a household are obtained by first solving for the dynamic equations for $c_t(z)$, $m_t(z)$, and $l_t(z)$. To begin I obtain the optimal non-medical consumption to medical consumption ratio from (3.7a) and (3.7b):

$$\frac{c_t(z)}{m_t(z)} = \frac{\theta_c}{\theta_m}\kappa(z), \tag{3.10a}$$

Similarly, the medical and non-medical consumption-leisure ratios for ages $z < \ell$ are:

$$\frac{c_t(z)}{l_t(z)} = \frac{\theta_c}{\theta_l} w_t(1-\tau_w). \tag{3.10b}$$

$$\frac{m_t(z)}{l_t(z)} = \frac{\theta_m}{\theta_l \kappa(z)} w_t(1-\tau_w). \tag{3.10c}$$

Next, for ages $z < \ell$, I differentiate (3.7a) with respect to age z, divide by (3.7a), and substitute for (3.7d′) to obtain the following dynamic equation:

$$(1-\gamma\theta_c)\frac{c_t'(z)}{c_t(z)} - \gamma\theta_m \frac{m_t'(z)}{m_t(z)} - \gamma\theta_l \frac{l_t'(z)}{l_t(z)} = -\frac{\lambda_t'(z)}{\lambda_t(z)} = (1-\tau_k)r - \beta. \tag{3.11a}$$

For ages $z \geq \ell$, equation (3.11a) reduces to the following:

$$(1-\gamma\theta_c)\frac{c_t'(z)}{c_t(z)} - \gamma\theta_m \frac{m_t'(z)}{m_t(z)} = -\frac{\lambda_t'(z)}{\lambda_t(z)} = (1-\tau_k)r - \beta. \tag{3.11b}$$

Using equations (3.10a) and (3.10b) I can explicitly solve for the dynamic equation for non-medical consumption in terms of the dynamic equations for medical consumption and leisure (for working aged households) respectively:

$$\frac{c_t'(z)}{c_t(z)} = \frac{l_t'(z)}{l_t(z)} + g, \tag{3.11c}$$

$$\frac{c_t'(z)}{c_t(z)} = \frac{m_t'(z)}{m_t(z)}, \tag{3.11d}$$

where g is the constant growth rate of labor productivity, or the equilibrium economic growth rate described in equation (3.38″).

After substituting for $m_t'(z)/m_t(z)$ and $l_t'(z)/l_t(z)$ into (3.11a), I solve for the Euler equations for both $c_t(z)$ and $m_t(z)$ when the agent is working:

$$\frac{c_t'(z)}{c_t(z)} = \frac{m_t'(z)}{m_t(z)} = \frac{(1-\tau_k)r - \beta - \gamma\theta_l g}{1-\gamma} = \phi_1. \tag{3.11a$'$}$$

Substituting for (3.11a′) in (3.11c) yields the dynamic equation for leisure time

$$\frac{l_t'(z)}{l_t(z)} = \phi_1 - g. \tag{3.11c$'$}$$

The Euler equation for medical and non-medical consumption for retired agents is obtained by setting $m_t'(z)/m_t(z)$ equal to $c_t'(z)/c_t(z)$ in equation (3.11b) and rearranging terms[8]

$$\frac{c_t'(z)}{c_t(z)} = \frac{m_t'(z)}{m_t(z)} = \frac{(1-\tau_k)r - \beta}{1-\gamma(\theta_c+\theta_m)} = \phi_2. \tag{3.11b$'$}$$

The optimal consumption and time allocation plans for working households are obtained by integrating (3.11a′) and (3.11c′)

$$c_t(z) = c_{t-z+x}(x)e^{\phi_1(z-x)}, \tag{3.12a}$$

$$m_t(z) = m_{t-z+x}(x)e^{\phi_1(z-x)}, \tag{3.12b}$$

$$l_t(z) = l_{t-z+x}(x)e^{(\phi_1-g)(z-x)}. \tag{3.12c}$$

As equation (3.11b′) illustrates, the time allocation paths of medical and non-medical con-

[8]Remember that $l_t'(z)/l_t(z) = 0$ when the agent is retired.

sumption changes when the household retires, so that (3.12a) and (3.12b) become

$$c_{t+z}(z) = c_t(\ell)e^{\phi_2(z-\ell)} \tag{3.12a$'$}$$

$$m_{t+z}(z) = m_t(\ell)e^{\phi_2(z-\ell)} \tag{3.12b$'$}$$

In order to solve the model, equations (3.12a′) and (3.12b′) must be rewritten as functions of initial non-medical and medical consumption (i.e. $c_t(0)$ and $m_t(0)$). Therefore, after setting $x = 0$ in equations (3.12a) and (3.12b) and substituting for $c_t(\ell)$ and $m_t(\ell)$ in (3.12a′) and (3.12b′), I can solve for the retired households time paths of non-medical and medical consumption as functions of $c_t(0)$ and $m_t(0)$:

$$c_{t+z}(z) = c_{t-\ell}(0)e^{\phi_1\ell+\phi_2(z-\ell)} \tag{3.13a}$$

$$m_{t+z}(z) = m_{t-\ell}(0)e^{\phi_1\ell+\phi_2(z-\ell)} \tag{3.13b}$$

Finally, in order to close the model, I must solve the household's initial optimal level of leisure time in terms of initial non-medical consumption using equation (3.10b):

$$l_t(0) = \frac{\theta_l}{w_t(1-\tau_w)\theta_c}c_t(0), \tag{3.12c$'$}$$

where initial non-medical consumption is described in equation (3.17′).

By incorporating equations (3.8′) and (3.9) into the flow budget constraint presented in equation (3.4), the household's budget constraint can be equivalently be expressed as

$$R(z,x)a_t'(z) + R'(z,x)a_t(z) = R(z,x)[w_t(1-\tau_w)(1-l_t(z)) - p_t - c_t(z) - \kappa(z)m_t(z)]. \tag{3.14}$$

To derive the household's inter-temporal budget constraint at age x and time t, I integrate

(3.14) forward at age z and substitute for the transversality condition in equation (3.9)

$$\begin{aligned}&\int_x^\omega e^{-(1-\tau_k)r(z-x)}\left(\frac{S(z)}{S(x)}\right)c_{t+z-x}(z)dz+\int_x^\omega e^{-(1-\tau_k)r(z-x)}\left(\frac{S(z)}{S(x)}\right)\kappa(z)m_{t+z-x}(z)dz\\+&\int_x^\omega e^{-(1-\tau_k)r(z-x)}\left(\frac{S(z)}{S(x)}\right)p_{t+z-x}dz=a_t(x)+\Omega_t(x),\end{aligned}\tag{3.15}$$

where $\Omega_t(x)$ is the household's non-financial wealth, or "human wealth" as in Blanchard (1985):

$$\Omega_t(x)=\int_x^\ell e^{-(1-\tau_k)r(z-x)}\left(\frac{S(z)}{S(x)}\right)w_t(1-\tau_w)(1-l_{t+z-x}(z))dz.\tag{3.16}$$

Equation (3.15) can be rewritten as a function of only non-medical consumption by substituting for medical consumption and the private health insurance premium using equation (3.12b) and the equilibrium private health insurance premium defined later in equation (3.37′). Incorporating equation (3.12a), household consumption at any age x is

$$c_t(x)=\mu(x)^{-1}[a_t(x)+\Omega_t(x)],\tag{3.17}$$

where $\mu(x)^{-1}$ is the marginal and average propensity to consume for the household at age x, and is expressed as follows:

$$\begin{aligned}\mu(x)=&\int_x^\ell e^{[\phi_1-(1-\tau_k)r](z-x)}\frac{S(z)}{S(x)}dz+\int_\ell^\omega e^{\phi_1\ell+\phi_2(z-\ell)-(1-\tau_k)r(z-x)}\frac{S(z)}{S(x)}dz+\frac{\theta_m}{\theta_c}\int_x^{zm}e^{[\phi_1-(1-\tau_k)r](z-x)}\frac{S(z)}{S(x)}dz\\&+\frac{\theta_m\kappa(z\geq zm)}{\theta_c\kappa(z<zm)}\int_{zm}^\ell e^{[\phi_1-(1-\tau_k)r](z-x)}\frac{S(z)}{S(x)}dz+\frac{\theta_m\kappa(z\geq zm)}{\theta_c\kappa(z<zm)}\int_\ell^\omega e^{\phi_1\ell+\phi_2(z-\ell)-(1-\tau_k)r(z-x)}\frac{S(z)}{S(x)}dz\\&+\frac{\theta_m}{\theta_c\kappa(z<zm)\Sigma^N}\left(\kappa_p(z<zm)\int_x^{zm}e^{(\phi_1-n)(z-x)}\frac{S(z)}{S(x)}dz\times\int_x^{zm}e^{-(1-\tau_k)r(z-x)}\frac{S(z)}{S(x)}dz\right.\\&\qquad+\kappa_p(z\geq zm)\int_{zm}^\ell e^{(\phi_1-n)(z-x)}\frac{S(z)}{S(x)}dz\times\int_{zm}^\ell e^{-(1-\tau_k)r(z-x)}\frac{S(z)}{S(x)}dz\\&\qquad\left.+\kappa_p(z\geq zm)\int_\ell^\omega e^{\phi_1\ell+\phi_2(z-\ell)-n(z-x)}\frac{S(z)}{S(x)}dz\times\int_\ell^\omega e^{-(1-\tau_k)r(z-x)}\frac{S(z)}{S(x)}dz\right),\end{aligned}\tag{3.18}$$

where Σ^N is the population aggregator defined in equation (3.25).

For simplicity, I assume that each agent working at calendar time t receives the same wage w_t. Additionally, I assume that labor productivity increases at an endogenously-determined constant rate g, implying that the market wage will grow at the same rate.[9] Consequently, for any household age x and at time t, the equilibrium market wage will be

$$w_t = w_{t-x}e^{gx}. \tag{3.19}$$

Therefore, incorporating equation (3.19) into equation (3.16) allows me to re-express the equation for human wealth as $w_t\Omega(x)$, where $\Omega(x)$ is the time-invariant present value discount factor for wage income

$$\Omega(x) = \int_x^\ell e^{[g-(1-\tau_k)r](z-x)}\left(\frac{S(z)}{S(x)}\right)(1-\tau_w)(1-l_t(x)e^{(\phi_1-g)(z-x)})dz. \tag{3.20}$$

$\Omega(x)$ differs from the present value discount factor in Bruce and Turnovsky (2013) in that labor supply is now endogenous and there are no Social Security payments to retired agents.

Each household is assumed to enter the economy without financial wealth (i.e. $a_t(0) = 0$). Therefore, from equation (3.17), initial non-medical consumption will be equal to

$$c_{t-x}(0) = \mu(0)^{-1}\Omega_{t-x}(0). \tag{3.17$'$}$$

Combining equations (3.12a), (3.17′), and (3.19) implies that non-medical consumption for working households will be equal to

$$c_t(x) = w_t e^{(\phi_1-g)x}\mu(0)^{-1}\Omega(0) \tag{3.21a}$$

[9]The production technology that results in endogenous growth and the derivation of the equilibrium growth rate are described in Sections 3.4.1 and 3.4.4

As a corollary, medical consumption at time t and age $x \leq \ell$ is

$$m_t(x) = \left(\frac{\theta_m}{\theta_c \kappa(z < zm)}\right) w_t e^{(\phi_1 - g)x} \mu(0)^{-1} \Omega(0).^{10} \tag{3.21b}$$

Similarly, combining equations (3.13a), (3.17′), and (3.19) solves for non-medical consumption for retired households:

$$c_t(x) = w_t e^{\phi_1 \ell + \phi_2 (x-\ell) - gx} \mu(0)^{-1} \Omega(0) \tag{3.22a}$$

Medical consumption at time t and age x of retired households is

$$m_t(x) = \left(\frac{\theta_m}{\theta_c \kappa(z \geq zm)}\right) w_t e^{\phi_1 \ell + \phi_2 (x-\ell) - gx} \mu(0)^{-1} \Omega(0). \tag{3.22b}$$

3.4 Aggregation

Let ψ_t be the size of the cohort that enters the economy at time t. The conditional probability of surviving to age x is $S(x)/S(0)$. Therefore, the size of a cohort at time t and age x is

$$N_t(x) = \psi_{t-x} \frac{S(x)}{S(0)}. \tag{3.23}$$

Additionally, I assume that the size of new cohorts grows at the constant rate n so that

$$\psi_t = \psi_{t-x} e^{nx}. \tag{3.24}$$

Therefore, I can express the population of each individual cohort as a function of the size of the entering cohort:

$$N_t(x) = \psi_t e^{-nx} \frac{S(x)}{S(0)}. \tag{3.23′}$$

[10] Note that $m_{t-x}(0) = [\theta_m / \kappa(z) \theta_c] c_{t-x}(0)$.

Finally, the aggregate population will be equal to the sum of the current population of all cohorts at time t:

$$N_t = \int_0^\omega N_t(x)dx = \psi_t \int_0^\omega e^{-nx}\frac{S(x)}{S(0)}dx = \psi_t \Sigma^N \tag{3.25}$$

Aggregate consumption of medical and non-medical goods is equivalent to the sum of the current consumption of each cohort at time t. Therefore aggregate non-medical consumption is expressed as

$$C_t = \int_0^\omega N_t(x)c_t(x)dx = w_t\psi_t\Sigma^C \tag{3.26a}$$

where Σ^C is the non-medical consumption aggregator

$$\Sigma^C = \left(\frac{\Omega(0)}{\mu(0)}\right)\left[\int_0^\ell e^{(\phi_1-g-n)x}\frac{S(x)}{S(0)}dx + \int_\ell^\omega e^{\phi_1\ell+\phi_2-g-n)x}\frac{S(x)}{S(0)}dx\right]. \tag{3.26b}$$

Note that equation (3.10a) indicates that optimal medical consumption at time t and age x is a function of optimal non-medical consumption, allowing aggregate medical consumption to be expressed as a function of aggregate non-medical consumption

$$\begin{aligned} M_t &= \int_0^\omega N_t(x)m_t(x)dx = \int_0^\ell m_t(0)e^{(\phi_1-g-n)x}\frac{S(x)}{S(0)}dx + \int_\ell^\omega m_t(0)e^{\phi_1\ell+\phi_2-g-n)x}\frac{S(x)}{S(0)}dx \\ &= \left(\frac{\theta^m}{\kappa(z<zm)\theta^c}\right)\left[\int_0^\ell c_t(0)e^{(\phi_1-g-n)x}\frac{S(x)}{S(0)}dx + \int_\ell^\omega c_t(0)e^{\phi_1\ell+\phi_2-g-n)x}\frac{S(x)}{S(0)}dx\right] \\ &= \left(\frac{\theta^m}{\kappa(z<zm)\theta^c}\right)w_t\psi_t\Sigma^C. \end{aligned} \tag{3.27}$$

The aggregate labor supply is the sum of the labor supplies of each age cohort

$$L_t = \int_0^\ell N_t(x)(1-l_t(0)e^{(\phi_1-g)x})dx = \psi_t\int_0^\ell e^{-nx}\frac{S(x)}{S(0)}(1-l_t(0)e^{(\phi_1-g)x})dx = \psi_t\Sigma^L. \tag{3.28}$$

Equation (3.28) implies that aggregate wage income is

$$w_t L_t = w_t \psi_t \Sigma^L. \tag{3.29}$$

3.4.1 Producers

The final goods sector is composed of L_t identical firms, each hiring one unit of labor and k_t units of capital. Each firm's after capital depreciation output is[11]

$$y_t = \hat{A} k_t^{\alpha} x_t^{1-\alpha} - \delta k_t \tag{3.30}$$

where δ is the depreciation rate of physical capital, $x_t = (G_t/L_t)^{\xi}(K_t/L_t)^{1-\xi}$ is a productivity externality,[12] where G_t is government infrastructure spending, and $k_t = K_t/L_t$ is the individual firms' capital stock, which is equal to the aggregate capital-labor ratio. Following Barro (1990), the productivity externality is the result of the interaction of the aggregate capital-labor ratio and government infrastructure investment per worker. Additionally, this specification implies that the productivity of capital is constant, allowing for stable equilibrium growth.

To prove this, consider aggregate after depreciation output, which is equal to the sum of the net output of all L_t firms ($Y_t \equiv y_t L_t$)

$$Y_t = \hat{A}\left(\frac{K_t}{L_t}\right)^{\alpha}\left(\frac{G_t}{L_t}\right)^{(1-\alpha)\xi}\left(\frac{K_t}{L_t}\right)^{(1-\alpha)(1-\xi)} L_t - \delta K_t, \tag{3.31}$$

[11] This production technology is employed by Bruce and Turnovsky (2013) and is an augmented version of Romer (1986) that includes government infrastructure spending following Barro (1990).

[12] The parameter ξ determines the size of the externaility, with $\xi = 0$ corresponding to the traditional Romer (1986) AK model and $\xi = 1$ corresponding to the stock version of Barro (1990) pioneered by Futagami et al. (1993).

which reduces to

$$Y_t = \hat{A} K_t^{1-(1-\alpha)\xi} G_t^{(1-\alpha)\xi} - \delta K_t.$$

If G_t is assumed to be fraction ν of gross output, then $G_t = \nu(Y_t + \delta K_t)$. Substituting for G_t, equation (3.31) reduces to

$$Y_t = (A - \delta) K_t, \tag{3.31$'$}$$

where $A = (\hat{A}\nu^{(1-\alpha)\xi})^{1/[1-(1-\alpha)\xi]}$. Incorporating (3.31′) into the equation for G_t yields

$$G_t = \nu A K_t. \tag{3.32}$$

The profit function for each firm at time t is

$$\Pi_t^f = y_t - r k_t - w_t. \tag{3.33}$$

Since all L_t firms are identical and the market for final goods is assumed to be perfectly competitive (i.e. $\Pi_t^f = 0$), there will be a single equilibrium interest rate and wage rate at any given time t. The equilibrium interest rate and wage rate are

$$r = \frac{\partial y_t}{\partial k_t} = \alpha A - \delta, \tag{3.33a}$$

$$w_t = (1 - \alpha) A k_t. \tag{3.33b}$$

Note that the equilibrium interest rate is constant and time-independent,[13] while the equilibrium wage rate will grow at the same rate as the aggregate capital-labor ratio (i.e. g).

[13] Changes to the infrastructure investment rate ν will result in a change of A, causing the interest rate to adjust to a new constant, time-invariant rate.

3.4.2 Government

There are three forms of government expenditures; infrastructure investment, government consumption C_t^g, and government medical expenditure transfers. Government infrastructure investment was briefly discussed in the preceding section and is assumed to be a fixed fraction of net aggregate output (see equation (3.32)). Similarly, I assume that government consumption is a fixed fraction η of aggregate output

$$C_t^g = \eta Y_t = \eta(A - \delta)K_t. \tag{3.34}$$

For simplicity, I assume that households do not receive utility from consumption of government consumption goods.

Government medical programs such Medicare, Medicaid, CHIP, the Department of Veteran's Affairs, etc. share many features of private health insurance, including co-pays, coinsurance rates, premiums, and deductibles. However, the primary source of revenue for these programs comes from federal and state tax receipts. For example, according to a study by the Kaiser Family Foundation (2014), beneficiary premium payments accounted for only 13 percent of Medicare's budget in 2013. Likewise, premiums may be charged to some Medicaid and CHIP recipients, but state and federal government tax revenues are still the primary source of financing for these two programs. Other programs such as the Veteran's Health Administration and the Indian Health Service directly provide health care services out of federal tax revenue. Similarly, the Department of Defense's TRICARE program provides direct health care services, while also providing military members with access to private health insurance and providers. Thus, for simplicity, I treat all medical expenditures financed by the government as pure transfers that are financed solely through capital and labor income tax receipts.[14]

[14]This is consistent with how NIPA treats government-financed medical expenditures, with 86.38 percent

Total government medical expenditures are

$$M_t^g = w_t \psi_t \Sigma^{MG}, \tag{3.35}$$

where Σ^{MG} is the aggregator for publicly-financed health care expenditures

$$\begin{aligned}\Sigma^{MG} = \left[\frac{\theta_m \Omega(0)}{\theta_c \mu(0)}\right] \Bigg[& \frac{\kappa_g(z < zm)}{\kappa(z < zm)} \int_0^{zm} e^{(\phi_1 - g - n)x} \frac{S(x)}{S(0)} dx \\ & + \frac{\kappa_g(z \geq zm)}{\kappa(z < zm)} \int_{zm}^{\ell} e^{(\phi_1 - g - n)x} \frac{S(x)}{S(0)} dx + \frac{\kappa_g(z \geq zm)}{\kappa(z < zm)} \int_{\ell}^{\omega} e^{\phi_1 \ell + \phi_2 (x - \ell) - (g+n)x} \frac{S(x)}{S(0)} dx \Bigg].\end{aligned}$$

I assume that the government must maintain a balanced budget at any point and time and cannot borrow. Hence, the government's budget constraint is

$$\tau_k r K_t + \tau_w w_t L_t = C_t^g + M_t^g + G_t. \tag{3.36}$$

Non-medical government consumption, government investment, and the capital tax rate are all exogenous. Similarly, the interest rate and the wage rate are determined by equilibrium in the financial and labor markets, while government medical expenditures and the aggregate labor supply are taken as given by the government. Consequently, the only option that government has is to choose the income tax rate that balances the budget, so that

$$\tau_w = \frac{C_t^g + M_t^g + G_t - \tau_k r K_t}{w_t L_t} = \frac{\eta(A - \delta)}{(1 - \alpha)A} + \frac{\nu}{1 - \alpha} + \frac{\Sigma^{MG}}{\Sigma^L} - \frac{\tau_k(\alpha A - \delta)}{(1 - \alpha)A}. \tag{3.36$'$}$$

3.4.3 Private Health Insurance Market

I assume that there are N_t identical private insurance firms in a perfectly competitive market. Each firm receives a premium p_t as revenue and covers a fixed fraction $k_p(z)$ of their

of government medical expenditures in the sample period classified as government transfers and only 13.62 percent classified as direct government consumption.

client's medical consumption that is based on the policyholder's age (i.e. $\kappa_p(z < zm)$ for $z < zm$ and $\kappa_p(z \geq zm)$ for $z \geq zm$). Further, I assume that each insurance firm insures an equal share of each cohort. This implies that the profit function for an individual insurance firm at time t will be

$$\Pi_t^i = p_t - w_t \frac{\Sigma^{MP}}{\Sigma^N}, \tag{3.37}$$

where Σ^{MP} is the privately-financed medical consumption aggregator

$$\Sigma^{MP} = \left[\frac{\theta_m \Omega(0)}{\theta_c \mu(0)}\right] \left[\frac{\kappa_p(z < zm)}{\kappa(z < zm)} \int_0^{zm} e^{(\phi_1 - g - n)x} \frac{S(x)}{S(0)} dx \right.$$
$$\left. + \frac{\kappa_p(z < zm)}{\kappa(z < zm)} \int_{zm}^{\ell} e^{(\phi_1 - g - n)x} \frac{S(x)}{S(0)} dx + \frac{\kappa_p(z < zm)}{\kappa(z < zm)} \int_{\ell}^{\omega} e^{\phi_1 \ell + \phi_2 (x - \ell) - (g+n)x} \frac{S(x)}{S(0)} dx \right]$$

Perfect competition in the health insurance market implies that each firm will earn zero profits ($\Pi_t^i = 0$) so that the premium rate is equal to

$$p_t = w_t \frac{\Sigma^{MP}}{\Sigma^N}, \tag{3.37$'$}$$

implying that aggregate premium payments will be equal to

$$P_t = p_t \psi_t \Sigma^N = w_t \psi_t \Sigma^{MP}. \tag{3.37$''$}$$

Equation (3.37$''$) implies that, in equilibrium, aggregate private health insurance premium payments will be equal to aggregate private health insurance payouts.

3.4.4 Economic Growth

To solve for the equilibrium growth rate of productivity, g, I first equate aggregate financial wealth to the aggregate capital stock K_t. This allows me to solve for the physical capital accumulation rate, by aggregating the flow budget constraint presented in equation

(3.4) over all age cohorts z:

$$\dot{K}_t = rK_t + w_tL_t - \tau_k rK_t - \tau_w w_t L_t - P_t - C_t - M_t^O \tag{3.38}$$

where M_t^O is out-of-pocket medical consumption defined as follows:

$$M_t^O = \left[\frac{w_t\psi_t\theta_m\Omega(0)}{\theta_c\mu(0)}\right]\left[\int_0^{zm} e^{(\phi_1-g-n)x}\frac{S(x)}{S(0)}dx \right. \\ \left. + \frac{\kappa(z\geq zm)}{\kappa(z<zm)}\int_{zm}^{\ell} e^{(\phi_1-g-n)x}\frac{S(x)}{S(0)}dx + \frac{\kappa(z\geq zm)}{\kappa(z<zm)}\int_{\ell}^{\omega} e^{\phi_1\ell+\phi_2(x-\ell)-(g+n)x}\frac{S(x)}{S(0)}dx\right]$$

Next, incorporating the government's budget constraint (3.36) and aggregate premium payments (3.37′′), plugging in the equilibrium interest and wage rates from equations (3.33a) and (3.33b), rearranging terms, and dividing by K_t, I can rewrite (3.38) as follows:

$$\frac{\dot{K}_t}{K_t} = \frac{Y_t}{K_t} - \frac{C_t^g}{K_t} - \frac{G_t}{K_t} - \frac{C_t}{K_t} - \frac{M_t}{K_t}, \tag{3.38′}$$

where $Y_t/K_t = A-\delta$, $C_t^g/K_t = \eta(A-\delta)$, $G_t/K_t = \nu A$, $C_t/K_t = (1-\alpha)A(\Sigma^C/\Sigma^L)$, and $M_t/K_t = [\theta_m/\theta_c\kappa(z<zm)](C_t/K_t)$.

Note that by definition, aggregate physical capital growth, $\dot{K}_t/K_t$, is equal to the sum of productivity growth, g, and population growth, n. Therefore, in equilibrium the productivity growth rate is equal to

$$g = (1-\nu-\eta)A - (1-\eta)\delta - \left(1+\frac{\theta_m}{\theta_c\kappa(z<zm)}\right)(1-\alpha)A\frac{\Sigma^C}{\Sigma^L} - n. \tag{3.38′′}$$

Note that the second to last term on the right hand side is equal to the sum of the non-medical and medical consumption-capital ratios C/K and M/K. Equation (3.38′′), the aggregator equations (3.25)-(3.28), (3.35), and the endogenous tax rate (3.36′) implicitly solve for the balanced growth rate, closing the model.

3.5 Calibration

Medicare Part D has had a significant impact on the aggregate average public medical expenditure share. According to MEPS, between 2001-2005 (prior to the implementation of Medicare Part D) the government financed 35.3 percent of all medical expenditures and 74 percent of the expenditures of those over 65. However, since 2006 government-financed medical expenditures accounted for 38.6 percent of all medical expenditures, and 76.6 percent of all expenditures by those over 65 were financed by the government. At the same time, the output share of medical consumption rose substantially prior to the implementation of Medicare Part D, averaging 12.65 percent between 2001-2005 versus 14.19 percent from 2006-2013.

Given the effect that Medicare Part D has had on the composition and magnitude of medical consumption in the US, in order to most accurately evaluate health care reform and changes to fiscal policy, I have chosen to calibrate the model to match the data after the implementation of Medicare Part D in 2006. For calibration, I utilize data from the National Income and Product Accounts (NIPA), supplemented by data from several other sources, including the National Health Expenditure Accounts (NHEA), the Penn World Tables 8.1 (PWT), the World Bank, MEPS, and the Social Security Life Tables (SSA).

NIPA includes total household expenditures of health care services and non-durable medical goods such as pharmaceuticals in their estimates of personal consumption expenditures (PCE), treating most government medical expenditures (i.e. Medicare, Medicaid, CHIP, etc.) as government transfers to households. Consequently, while there is a small fraction of government medical expenditures[15] that are counted as government consumption, the vast majority of government-financed medical expenditures are counted as part of PCE. Therefore, my estimates of public and private non-medical consumption presented in

[15] Approximately 0.9 percent of GDP

Table 3.1 are net of NIPA's estimates of public and private medical consumption, which NIPA estimates to be approximately 14.1 percent of GDP over the sample period, close to the estimate produced by NHEA (14.2 percent of GDP).

Table 3.1: US Data (2006-2013)

Variable	Value	Description; [Source]
C/Y	0.550	Private non-medical consumption-output ratio; [NIPA & NHEA]
C^g/Y	0.150	Public non-medical consumption-output ratio; [NIPA]
M/Y	0.142	Medical consumption-output ratio; [NIPA & NHEA]
M^p/Y	0.077	Private medical consumption-output ratio; [NIPA & NHEA]
M^g/Y	0.065	Public non-medical consumption-output ratio; [NIPA & NHEA]
Π/Y^*	0.056	Total premiums-output ratio; [NIPA & NHEA]
G/Y^{**}	0.256	Government expenditures-output ratio; [NIPA & NHEA]
L	0.294	Average annual hours worked per worker; [PWT 8.1]†
$1-L$	0.706	Leisure time per worker
τ_w	0.250	Average effective tax rate on labor income; [NIPA]
g^{***}	0.014	Average growth rate of real GDP per capita; [NIPA]
$LE20$	59.319	Life-expectancy at age 20; [SSA]
$LE65$	18.942	Life-expectancy at age 65; [SSA]

* Does not include Medicare premiums.
** Total government expenditures-output.
*** 1994-2013 average annual growth rate of real GDP per capita.
† Feenstra, Inklaar, and Timmer (2013), "The Next Generation of the Penn World Table."

Unfortunately, NIPA does not provide sufficient detail to calibrate the medical consumption-output ratios by the source of payment. However, since the NIPA and NHEA estimates of aggregate medical expenditures parallel each other, I can take advantage of the greater detail provided by NHEA to breakdown aggregate medical expenditures by the source of payment. Specifically, the model is calibrated to match three important output ratios; 1) Privately financed medical consumption M^p, or medical expenditures financed by either private health insurance or out-of-pocket payments by households. 2) Government financed medical consumption M^g, which I assume includes government health care transfers to households. 3) Aggregate premium payments Π, estimated from NHEA as medical expenditures financed by private health insurers plus the "net cost of health insurance," which is defined by NHEA as "the difference between premiums earned by insurers and the claims or losses incurred for which insurers become liable."

Finally, I use NIPA to estimate the aggregate government expenditures-output ratio G/Y, the average effective tax rate on labor income τ_w, and the balanced growth rate g. For the purposes of calibration I assume that aggregate government expenditures includes government investment (4.1 percent of GDP),[16] consumption (15 percent of GDP), and medical expenditures as defined in the preceding paragraph. The procedure I utilize to estimate τ_w was developed by Gomme and Rupert (2005) and is detailed in Section 2.4. To calibrate g, I use the average annual growth rate of real GDP per capita for the 20-year period from 1994-2013. The average time devoted to labor per working individual L/N predicted by the model is calibrated to match the PWT estimate of the average hours worked per person engaged in the labor market.

3.5.1 Parameters

Table A.2 in the Appendix lists the model's parameters, their values, and the source motivating the selection of these values. I assume that the inter-temporal elasticity of substitution is 0.5 (i.e. $\gamma = -1$), consistent with the range of estimates in Guvenen (2006). The preference parameters θ_c, θ_m, and θ_l are selected to match the medical and non-medical consumption-output ratios and time use allocation between labor and leisure presented in Table 3.1. The productivity parameters α and δ are equated to the literature standard values of 0.3 and 0.05 respectively. I assume that the before-tax interest rate r is equal to 7.87 percent and the capital tax rate is 15 percent following Chatterjee, Guiliano, and Turnovsky (2004). Therefore, the after-tax return to financial wealth $(1 - \tau_k)r$ is approximately equal to 6.7 percent (see Bruce and Turnovsky [2013]). The interest rate implies that total factor productivity A will be equal to 0.429.

[16]By definition $\nu = [0.041(A - \delta)]/A = .036$.

In Section 3.3 I briefly described the Gompertz survival function that characterizes the household's survival function. Again, following Bruce and Turnovsky, I assume that the maximum attainable age is 95 years old (i.e. $\omega = 75$) and that all household's will be fully retired by age 78 (i.e. $\ell = 58$). In addition, I also assume that ρ is equal to 0.0566[17] to match the life-expectancies estimates at ages 20 and 65 from SSA. The population growth rate is set to 0.8 percent to match the average annual growth rate of the US population from the sample period according to population estimates from the World Bank.

Unfortunately, NHEA only provides aggregated medical expenditure data. Therefore, to calibrate the private and government shares of medical expenditures, I utilize data from MEPS. Specifically, for each individual in the sample I generated an estimate of their total expenditures resulting from any inpatient, outpatient, and/or ER stays they had in the past year. Then, I calculated the fraction of these expenditures by the source of payment (i.e. out-of-pocket, private health insurance, or any government organization). Next, after applying sample weights, I divided the sample population into two categories, individuals under 65 years old and those 65 and up, providing estimates for the medical expenditure shares for young and old households.

3.5.2 Results

Table 3.2 compares the results of the model to US data from 2006-2013. I calibrate the model to match the aggregate medical consumption-output ratio (M/Y), the average annual growth rate for the 20 year period 1994-2013 (g), average life-expectancy at ages 20 and 65 ($LE20$ and $LE65$), and the average time allocation of working households (L). The aggregate M/Y ratio equals the observed level from the data, with the model slightly over-predicting aggregate the private medical consumption-output ratio (0.087 versus 0.077). Additionally, the model over-predicts the aggregate non-medical consumption-output ratio

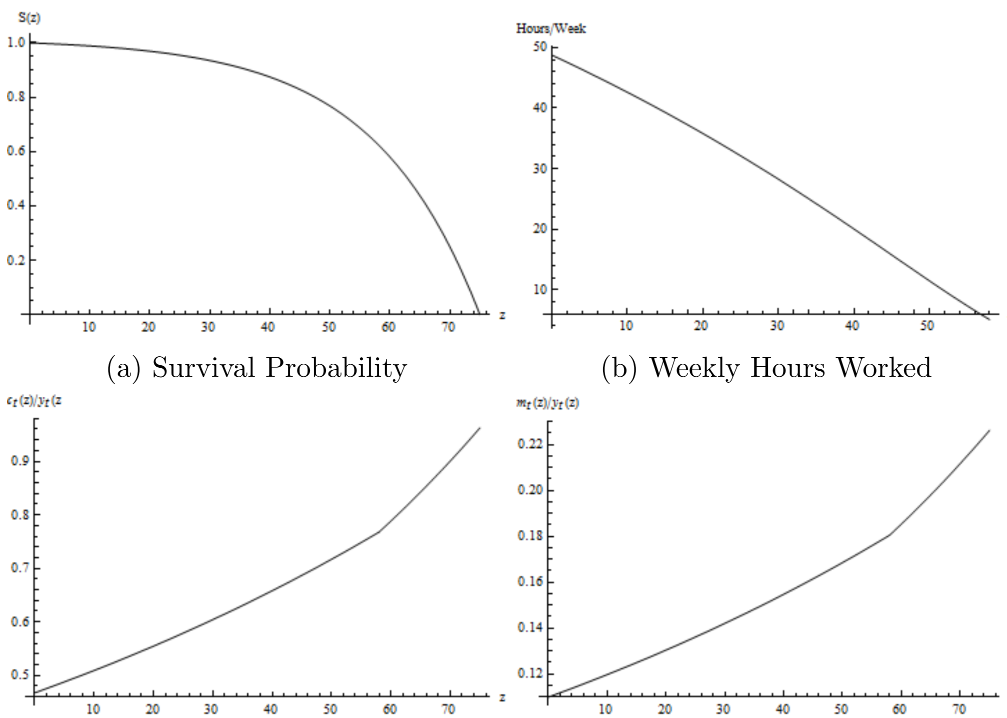
[17] Bruce and Turnovsky (2013) set $\rho = 0.0566$ to match the life-expectancy of 65 year old females.

(C/Y) and labor income tax rate (τ_w) by 5.5 and 2.1 percentage points respectively. Finally, the time allocations, life-expectancies, and growth rate are very close to the observed levels from the data.

Table 3.2: Exogenous Mortality vs. Data (2006-2013)

	C/Y	M/Y	M^p/Y	M^g/Y	Π/Y^*	L	$1-L$	τ_w	$LE20$	$LE65$	g^{**}
Data	0.550	0.142	0.077	0.065	0.056	0.294	0.706	0.250	59.319	18.942	0.014
Model	0.605	0.142	0.087	0.055	0.066	0.293	0.707	0.271	58.423	19.054	0.015

* Does not include Medicare premiums.
** 20-year average annual growth rate of real GDP per capita (1994-2013).



(a) Survival Probability (b) Weekly Hours Worked

(c) Consumption-Per Capita Output (d) Medical-Per Capita Output

Figure 3.2: Lifetime Time Paths

The expected lifetime time paths of the survival probability, average weekly hours worked, non-medical consumption-per capita output ratio, and medical consumption-per capita output ratio for a representative household are presented above in Figure 3.2. The household's survival probability declines slowly initially. The rate of decline increases rapidly as the household nears the maximum attainable age. As can be seen from panel (b), the representative household supplies just under 48.75 hours of labor per week when it enters the economy. Its labor supply declines steadily throughout its working life, falling to just over 8 hours per week just before retirement at age 78. Both the medical and non-medical consumption-output ratios increase at the same rate throughout the household lifetime. When the household retires consumption of both goods accelerates as the households consumes its remaining savings and life annuity premium payments.

3.6 Growth Rate and Welfare Analysis

In this section I analyze the long-run impact on the equilibrium growth rate and aggregate welfare of several health and fiscal policy reform scenarios. These scenarios include a one percent increase in the private and public medical expenditure shares ($\kappa_p(z)$ and $\kappa_g(z)$),[18] government investment (ν), and government consumption (η). In addition, I also examine the effect of increasing the Medicare eligibility age to 67 (zm), a frequently proposed reform to Medicare.

The welfare and growth analysis is conducted as follows: I compare the expected lifetime utility of a representative individual belonging to the cohort born at time t in the benchmark economy with that of a representative individual born at time t under the new economic conditions in the counterfactual economy. Equations (3.2) and (3.3) present the expected remaining lifetime utility of an individual at time t and age x. Assuming that the representative individual was born at time t (i.e. set $x = 0$), his expected lifetime utility at

[18] I assume that both the young and the old rates rise by 1 percent simultaneously.

age 20 is expressed as

$$u_t(0) = \int_0^{\omega} e^{-\beta z} \left(\frac{S(z)}{S(0)}\right) \frac{[c_{t+z}(z)^{\theta_c} m_{t+z}(z)^{\theta_m} l_{t+z}(z)^{\theta_l}]^{\gamma}}{\gamma} dz \tag{3.39}$$

Noting that $l_t(z) = 1$ for $z \geq \ell$, equation (3.39) can be rewritten as follows:

$$\begin{aligned} u_t(0) =& \int_0^{\ell} e^{-\beta z} \left(\frac{S(z)}{S(0)}\right) \frac{[c_{t+z}(z)^{\theta_c} m_{t+z}(z)^{\theta_m} l_{t+z}(z)^{\theta_l}]^{\gamma}}{\gamma} dz \\ &+ \int_{\ell}^{\omega} e^{-\beta z} \left(\frac{S(z)}{S(0)}\right) \frac{[c_{t+z}(z)^{\theta_c} m_{t+z}(z)^{\theta_m}]^{\gamma}}{\gamma} dz. \end{aligned} \tag{3.39$'$}$$

Substituting for $c_{t+z}(z)$, $m_{t+z}(z)$, and $l_{t+z}(z)$ from equations (3.12a)-(3.13b) yields

$$u_t(0) = w_t^{\gamma(\theta_c+\theta_m)} \tilde{u}, \tag{3.40a}$$

where $\tilde{u}$ is the time-independent utility multiplier defined as

$$\begin{aligned} \tilde{u} = \frac{1}{\gamma} \left[\frac{\theta_m}{\theta_c \kappa(z)}\right]^{\gamma\theta_m} \left[\frac{\Omega(0)}{\mu(0)}\right]^{\gamma(\theta_c+\theta_m)} &\left[l_t(0)^{\gamma\theta_l} \int_0^{\ell} e^{[\gamma(\theta_c+\theta_m)+\gamma(\phi_1-g)-\beta]z} \left(\frac{S(z)}{S(0)}\right) dz \right. \\ &\left. + \int_{\ell}^{\omega} e^{\{\gamma(\theta_c+\theta_m)[\phi_2(z-\ell)+\phi_1\ell]-\beta z\}} \left(\frac{S(z)}{S(0)}\right) dz \right]. \end{aligned} \tag{3.40b}$$

Equations (3.40a) and (3.40b) imply that it is not enough to consider only the effect that a policy change has on either the growth rate or the utility multiplier. Instead, both must be considered concurrently. For example, if both the growth rate and the utility multiplier rise in response to a change in the economy, then I can conclude that welfare for all existing and future individuals will rise. Similarly, I can conclude that welfare will fall for both current and future generations if both the growth rate and the utility multiplier decline. However, if g and $\tilde{u}$ move in different directions the ultimate result for future generations will be ambiguous.[19]

[19]If $\partial g < 0$ and $\partial \tilde{u} > 0$, then the current generations are better off, while future generations may be worse

Table 3.3 displays the results from each of the five policy experiments. Each value in the table represents the percent difference between the counterfactual economy and the benchmark economy.

Table 3.3: Percent Change of Equilibrium Variables (Exogenous Mortality)

	C/Y	M/Y	M^p/Y	M^g/Y	Π/Y	L	$1-L$	τ_w	g^*	$\tilde{u}$
κ_p	-0.590	2.587	2.571	2.613	3.596	0.251	-0.104	0.670	-0.266	-0.184
κ_g	-0.243	1.079	0.432	2.104	1.070	0.035	-0.015	0.540	-0.151	-0.083
ν	-0.106	-0.106	-0.140	-0.053	-0.140	0.004	-0.002	0.190	1.718	0.060
η	-0.198	-0.198	-0.201	-0.192	-0.201	-0.029	0.012	0.650	-0.057	-0.068
$zm^\dagger$	0.034	0.034	2.404	-3.721	2.418	0.246	-0.102	-0.954	-0.635	-0.112

* 20-year average annual growth rate of real GDP per capita (1994-2013).
† Increase the Medicare eligibility age to 67.

3.6.1 Private Health Insurance Share of Medical Expenditures

The private mandate contained in the ACA requires that households acquire health insurance. If successful, over the next decade the fraction of privately insured households should rise as previously uninsured households (or households that would have been uninsured if the law hadn't existed) enroll in private health insurance plans. Consequently, the private health insurance share of medical consumption should rise. To simulate the potential effect this new policy will have on growth and welfare, I assume that both $\kappa_p(z < zm)$ and $\kappa_p(z \geq zm)$ will rise by one percent.

A one percent increase to both $\kappa_p(z < zm)$ and $\kappa_p(z \geq zm)$ reduces the out-of-pocket cost of medical care $\kappa(z)$ to the households. Naturally, households in the counterfacutal economy devote a larger portion of their income to medical consumption, and a smaller portion of their income to non-medical consumption relative to the benchmark economy. As a result, the non-medical consumption-output ratio (C/Y) declines by 0.590 percent while the medical consumption-output ratio (M/Y) rises by 2.587 percent. The increase in private

off. If $\partial g > 0$ and $\partial \tilde{u} < 0$, then the current generations are worse off, while future generations may be better off.

medical consumption combined with the one percent rise of both $\kappa_p(z < zm)$ and $\kappa_p(z \geq zm)$ result in a 3.596 percent increase in the premium-output ratio (Π/Y).

Interestingly, both publicly and privately-financed medical consumption rise relative to output (2.613 percent and 2.571 percent respectively), despite the fact that the public share of medical expenditures is unaffected. However, since the out-of-pocket cost of health care has declined, the optimal level of medical consumption has risen at every age, raising public medical expenditures.

The aggregate consumption-capital $(C_t + M_t)/K_t$ rises so that the growth rate g declines by 0.266 percent, causing the household's lifetime income to decline. Additionally, the rise in public medical expenditures raises the income tax rate τ_w by 0.670 percent, further reducing the household's disposable income. Therefore, households increase their labor supply, so that the average labor supply of working individuals increases by 0.251 percent, corresponding to a 0.104 decline in average leisure time per worker. The decline of non-medical consumption, leisure time, and the growth rate all have a negative effect on the utility multiplier $\bar{u}$, while rising medical consumption has a positive effect on $\bar{u}$. Ultimately, counterfactual $\bar{u}$ is 0.184 percent lower than in the benchmark economy. This decline, combined with the lower growth rate implies that households in the counterfactual economy will worse off in the both the short-run and the long-run.

3.6.2 Public Share of Medical Expenditures

In Section 3.2 I discussed the effect that the ACA has already had on enrollment in Medicaid and CHIP. Additionally, I also discussed the rise in Medicare payouts that have occurred since the institution of Medicare Part D. To simulate the effect of both of these reforms on the economy, I assume that both $\kappa_g(z < zm)$ and $\kappa_g(z \geq zm)$ are increasing by one percent.

As was the case in the preceding subsection, the out-of-pocket cost of medical consumption has declined, prompting households in the counterfactual economy to devote a smaller portion of their income to non-medical consumption in favor of greater medical consumption. As a result, the counterfactual C/Y ratio will be 0.243 percent below the benchmark, while the counterfactual M/Y ratio will be 1.079 percent above the benchmark. Intuitively, the public medical consumption-output ratio (M^g/Y) increases, rising by 2.104 percent, inducing a 0.540 percent increase in the income tax rate.

Somewhat surprisingly, the private medical consumption-output ratio (M^p/Y) also rises, increasing by 0.432 percent, despite the fact that $\kappa_p(z < zm)$ and $\kappa_p(z \geq zm)$ are unaltered. This result arises from the reduction in the out-of-pocket cost of health care which causes the optimal level of medical consumption to rise at every age. The modest increase in the privately-financed medical consumption causes private health insurance premiums to rise, resulting in a 1.070 percent rise in the Π/Y ratio.

Aggregate savings falls, causing the growth rate to fall by 0.151 percent. This, combined with the increase to the income tax rate, reduces lifetime non-financial wealth. The decrease in the household's lifetime disposable income is small enough that the income effect will dominate, so that the household will increase its labor supply. Ultimately, the utility multiplier falls as non-medical consumption, leisure time, and the growth rate all decline. The diminished growth rate and utility multiplier combine to imply that both current and future households are worse off as a result of this new fiscal policy.

Before considering the next scenario, I want to briefly discuss how the predictions of the model relate to estimates of the price elasticity of medical expenditures. A one percent rise of $\kappa_p(z < zm)$ results in a decrease of $\kappa(z < zm)$ of approximately 3.1 percent, while a one percent rise of $\kappa_g(z < zm)$ leads to a decline of $\kappa(z < zm)$ of more than 1.3 percent. In response, initial medical consumption rises by 2.587 percent and 1.079 percent respectively, implying out-of-pocket elasticity of approximately -0.83. This elasticity represents a lower bound, as a decrease to out-of-pocket costs causes the household's lifetime income to decline, and since health care is a normal good, declining lifetime income will have a negative effect on medical consumption.

How does this elasticity compare with estimates from the rest of the literature? Manning et al. (1987) is perhaps the most well know empirical estimate of the price elasticity of medical expenditures. Using experimental data, they estimated a price elasticity of around -0.2, significantly below the price elasticities implied by my model. Several other studies have found similar price elasticities (see Table 3 of Borger et al. [2008]), suggesting that the price elasticity of medical is relatively inelastic.

However, there have been many studies that have found price elasticities that are much larger. One example from the literature is Gerdtham and Jonsson (1991), who estimate a price elasticity of -0.84 using health care expenditures from 22 OECD countries. Another example is Eichner (1998), who estimated that a price elasticity between -0.62 to -0.75 using insurance claims from a single large employer. Finally, a very recent study by Kowalski (forthcoming) estimates a range of elasticities from -0.76 to -1.49. Consequently, there is enough empirical evidence supporting a price elasticity of health care demand that is somewhere between 0 and -1.

3.6.3 Government Investment

The productivity externality x_t implies that increases to the rate of government investment (ν) will have a direct and positive effect on productivity (A),[20] which is in turn positively correlated with the growth rate (see equation (38″)). However, equation (38″) also implies that increases to government investment have a direct, adverse effect on the growth rate. Similarly, additional government investment has an indeterminate effect on the aggregate consumption-capital ratio, which is negatively correlated with the growth rate. Thus,

[20] Remember that $A = (\hat{A}\nu^{(1-\alpha)\xi})^{1/[1-(1-\alpha)\xi]}$.

the effect of a one percent increase in the rate of government investment on the growth rate is ambiguous.

Row 3 of Table 3.3 displays the percent change from the benchmark economy that results from a one percent increase in the government investment rate. The subsequent increase in productivity (0.411 percent) that arises from the productivity externality causes the growth rate in the counterfactual economy to rise by 1.718 percent relative to the benchmark growth rate. The rise in productivity also causes the interest rate to increase by 0.672 percent. Households respond to the rise in the interest rate by increasing their savings, so that C/Y and M/Y fall by 0.106 percent.

A portion of the new government investment is financed by the additional tax revenue generated by the rise in productivity, while the rest is financed by a modest 0.190 percent increase to the labor income tax rate. Average labor time per worker increases by 0.004 percent, reducing average labor time per worker by 0.002 percent. The utility multiplier increases by 0.060 percent as households benefit from the higher growth rate, despite the fact that leisure time and medical and non-medical consumption all decline. Therefore, I can conclude that raising the rate of government investment is beneficial in both the short-run and the long-run.

3.6.4 Government Consumption

Households respond to a one percent increase in the government consumption-output ratio (η) by decreasing consumption of both goods by 0.198 percent relative to output. Both private and public medical consumption fall relative to output by 0.201 and 0.192 percent respectively. The positive effect on the labor income tax rate that arises from the increase in non-medical government consumption outweighs the negative effect arising from the decrease in public medical expenditures, causing the labor income tax rate to rise by 0.650 percent.

Equation (38$''$) implies that there is a negative correlation between η and the growth rate, so that a one percent increase of η will cause the the growth rate to fall. At the same time, the increase to η causes the aggregate consumption-capital ratio to decline, offsetting some of the negative effect on the growth rate, leading to a 0.057 percent decline of the growth rate. This prediction is consistent with Barro's (1991) cross-sectional study of 98 countries between 1960-1985, in which he concludes that η has a significant and negative effect on the growth rate of real GDP per capita.[21]

The increase of the labor income tax rate, combined with the decline to the growth rate, reduces the after-tax return to labor. This prompts households to reduce their lifetime labor supply, leading to a 0.029 percent decrease in the average labor supply per worker (equivalent to a 0.012 percent increase in average leisure time per worker). The decline in medical and non-medical consumption and the growth rate outweigh the utility gains from increased leisure time, causing the multiplier to fall by 0.068 percent. Consequently, increasing non-medical government consumption has negative welfare and growth consequences in both the long-run and the short-run.

3.6.5 Medicare Eligibility Age

The intuition behind raising the Medicare eligibility age from 65 to 67 was briefly discussed in Section 3.2. The model predicts that government medical expenditures will fall by 3.721 percent, allowing the government to cut the labor income tax rate by 0.954 percent. As a result, I can conclude that this reform will be successful in cutting the cost of health care to the government. Curiously, even though M^g/Y declines considerably, M/Y actually increases by 0.034 percent. Raising the eligibility age means that households will primarily be covered by private health insurance for two additional years. Naturally, M^p/Y will increase,

[21] He regresses the average annual growth rate of real GDP per capita from 1960-1985 on η and other explanatory variables. He estimates that the coefficient on of η of -0.12.

rising by 2.404 percent, corresponding to a 2.418 percent increase in the Π/Y ratio. The rise in privately-financed medical consumption outweighs the fall in publicly-financed medical consumption, resulting in the small increase in medical consumption relative to output.

The rise of aggregate consumption relative to output in this scenario can be partially explained by the existence of life annuities in the model. Since the household receives life annuities in retirement, they will respond to the decline in the labor income tax rate by saving less so that C/Y and M/Y rise by 0.034 percent. If there were no life annuities, then raising the Medicare eligibility age would significantly increase the cost of health care when the household is old (especially if the annuities are replaced by a Social Security program with an eligibility age is also rising). If life annuities were absent, then it is likely that households would increase their savings to pay for the two additional years with higher out-of-pocket costs.

Diminished savings leads to a decline in the growth rate of 0.635 percent. Working households increase their average labor supply by 0.246 percent in response to the increase in the after-tax wage rate. Average leisure time per worker falls by 0.102 percent. Decreased leisure time together with the lower growth rate cause the utility multiplier to fall by 0.112 percent, making the economy worse off. However, to reiterate, the effect on savings may be reversed if Social Security replaced the life annuities and the eligibility age of Social Security and Medicare both increase. As a result, the sign of some of the predicted results may flip, making this policy welfare-enhancing in the long-run rather than reducing.

Chapter 4

Heath Care and Fiscal Policy Reform With Endogenous Mortality

4.1 Endogenous Survival Probability

In this chapter I relax the exogenous mortality assumption and allow the household's survival probability to be a function of the household's current age and medical consumption. In order to preserve tractability of the model, the survival probability must remain time-invariant. Unfortunately, tying the survival probability to medical consumption would cause $S(z)$ to become time-dependent since $m_t(z)$ is a function of the current wage rate w_t (see equations (3.21b) and (3.22b)). To avoid this problem, I assume that the household's survival probability is a function of its current medical consumption relative to the wage rate that prevailed when the household entered the economy w_{t-x}.[1]

The endogenous survival probability for an age z household is

$$S(z) = \Gamma(z) \left(\frac{m_t(z)}{w_{t-z}} \right)^{\sigma} \tag{4.1}$$

[1] $w_{t-x} = w_t e^{-gx}$

where $\Gamma(z)$ describes the productivity of health investment at age z, $m_t(z)/w_{t-z}$ is the medical consumption-initial wage ratio, and $0 < \sigma < 1$ is the elasticity of survival with respect to medical consumption. Substituting (3.21b) for $m_t(z)$ and noting that $w_{t-z} = w_t e^{-gz}$, the survival probability for an age $z < \ell$ household can be rewritten as follows:

$$S(z) = \Gamma(z)\left(\frac{w_t \theta_m \Omega(0) e^{(\phi_1 - g)z}}{w_t e^{-gz}[\theta_c \kappa(z < zm)\mu(0)]}\right)^{\sigma} = \Gamma(z)\left(\frac{\theta_m \Omega(0) e^{\phi_1 z}}{\theta_c \kappa(z < zm)\mu(0)}\right)^{\sigma}. \tag{4.2a}$$

Similarly, using (3.22b), I can substitute for $m_t(z)$ in (4.1), so the survival probability for age $z \geq \ell$ households becomes

$$S(z) = \Gamma(z)\left(\frac{\theta_m \Omega(0) e^{\phi_1 \ell + \phi_2(z-\ell)}}{\theta_c \kappa(z < zm)\mu(0)}\right)^{\sigma}. \tag{4.2b}$$

In order to maintain continuity with the exogenous case, I assume that health investment productivity is identical to the exogenous survival probability described in equation (4.1):

$$\Gamma(z) = \frac{e^{\rho(\omega)} - e^{\rho z}}{e^{\rho(\omega)} - 1}, \tag{4.3}$$

where ρ determines the rate at which health investment productivity declines with age. Note that since $\Gamma(z)$ is identical to the exogenous survival probability, $\sigma = 0$ is a special case where the endogenous and exogenous survival probabilities are identical.

The mortality hazard rate of age $z < \ell$ households is obtained by differentiating (4.2a) with respect to age and dividing by (4.2a):

$$\frac{S'(z)}{S(z)} = \frac{\Gamma'(z)}{\Gamma(z)} + \sigma\phi_1, \tag{4.4a}$$

while the mortality hazard rate for age $z \geq \ell$ households is

$$\frac{S'(z)}{S(z)} = \frac{\Gamma'(z)}{\Gamma(z)} + \sigma\phi_2. \tag{4.4b}$$

Note that the rate of change of the survival probability is a function of the rate of change of health investment productivity and medical consumption over the household's lifetime. I assume that health investment productivity declines with age, while medical consumption grows throughout the household's lifetime. To ensure that the survival probability falls with age, I calibrate health investment so that $|\Gamma'(z)/\Gamma(z)| > \sigma m_t'(z)/m_t(z)$.

Equation (4.4a) demonstrates the relationship between economic growth and longevity. From equation (3.11a′) I can infer that the growth rate of medical consumption for working household ϕ_1 is a function of the growth rate g. The relationship between the growth of medical consumption and the economic growth rate is determined by the sign of γ. Since I set $\gamma = -1$, ϕ_1 will rise in response to an increase in the growth rate g. Consequently, increases to the growth rate cause the survival probability to decline at a slower rate when the household is working, increasing longevity.

The endogenous mortality hazard rates defined by (4.4a) and (4.4b) reveal another important difference between the exogenous and endogenous survival probabilities. In the exogenous mortality case, there is a single function that describes the mortality hazard rate $S'(z)/S(z)$, implying that $S(z)$ is a continuous and smooth function. Whereas in the endogenous mortality case, there are two equations describing the mortality hazard rate, resulting in a kink in the endogenous survival probability, making it continuous, but not smooth (see Figure 3.2).

The kink in the survival function exists because of the increase in the growth rate of medical consumption that occurs when the household retires. The post-retirement rise in the rate of health investment alters the path of the household's survival probability, slowing its rate of decline. The existence of this kink implies that there is no longer a single equation that describes the conditional probability of surviving from the time the household enters the economy to age z, $S(z)/S(0)$. In both the exogenous and endogenous mortality cases, $S(0) = 1$, so that the $S(z)/S(0) = S(z)$. Consequently, there are now two equations, (4.2a) and (4.2b), that describe the conditional probability.

In order to maintain continuity with the exogenous case, I assume that households do not internalize the effect that medical consumption has on their survival probability. This assumption implies that the Hamiltonian and the resulting first-order conditions are unaltered from the exogenous mortality case. However, the kink in the survival probability must be accounted for when solving for the model analytically.

4.2 Results

As I noted above, the exogenous mortality model is a special case of the endogenous mortality model, where $\sigma = 0$ and $\rho = 0.0566$. I compare the results from the exogenous model with those from the endogenous mortality model with three separate values for the elasticity of survival with respect to health care, $\sigma = \{0.05, 0.2, 0.5\}$. I select values for ρ to match US life expectancy as closely as possible, while also ensuring that $S(z) \leq 1$ at all ages.

The balanced growth path results predicted by the endogenous mortality version are compared with the results from the exogenous mortality version in Table 4.1.

Table 4.1: Robustness Check: Endogenous Mortality

	C/Y	M/Y	M^p/Y	M^g/Y	L	$1-L$	τ_w	$LE20$	$LE65$	g^*
$\sigma = 0$, $\rho = .0566^\dagger$	0.6053	0.1423	0.0872	0.0550	0.2927	0.7073	0.2709	58.423	19.054	0.0154
$\sigma = .05$, $\rho = .05$	0.6055	0.1423	0.0873	0.0549	0.2923	0.7077	0.2708	58.954	18.877	0.0153
$\sigma = .2$, $\rho = .024$	0.6064	0.1425	0.0893	0.0532	0.2894	0.7106	0.2686	55.352	17.697	0.0149
$\sigma = .5$, $\rho = .003$	0.6068	0.1426	0.0900	0.0526	0.2884	0.7116	0.2678	53.890	17.308	0.0147

* 20-year average annual growth rate of real GDP per capita (1994-2013).
† Corresponds to the exogenous mortality case.

As can be seen from Table 4.1, most of the model's predictions are not significantly altered when the survival probability becomes endogenous. As σ rises (i.e. health care consumption has a greater effect on longevity) the consumption share of output rises slightly, causing the growth rate to decline. Average labor time per worker falls from 0.2927 in the exogenous model to 0.2884 when $\sigma = 0.5$. The labor income tax rate falls slightly, but is essentially unaltered from the exogenous case.

Interestingly, life expectancy and σ appear to be inversely related. This relationship can be explained by the decline of the productivity parameter ρ that coincides with the increase of σ. The parameter ρ embodies all of the exogenous factors that influence the productivity of health investment, such as the current level of medical technology in the economy or genetic and environmental factors that influence the prevalence of disease. Lower values of ρ correspond to sharper declines to health investment productivity (see Figure 4.1).

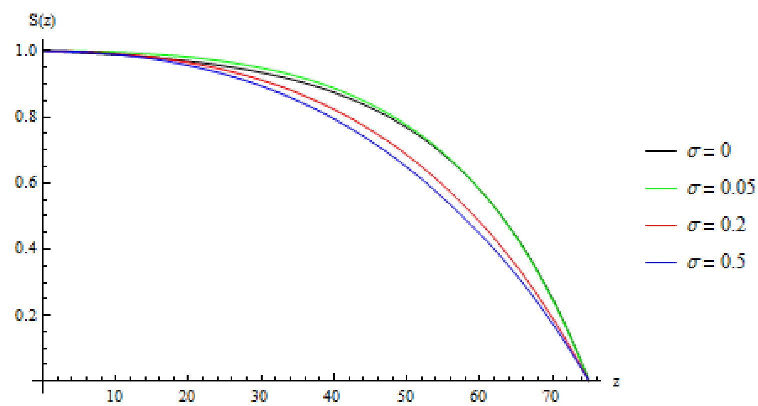


Figure 4.1: Endogenous Survival Probability

Setting $\sigma = 0.05$ slightly improves the performance of the model. Life expectancy at both age 20 and at age 65 are slightly closer to the observed life expectancies in the data. Increasing σ from 0.05 to 0.2 significantly alters life expectancy, reducing it to 55.352 years at age 20, over 3 years below the exogenous life expectancy, and nearly 4 years below the life expectancy observed in the data. Therefore, the endogenous model with $\sigma = 0.05$ and

$\rho = 0.05$ appears to be the version that most accurately matches the data, implying that medical consumption has a small, albeit positive effect on longevity. However, consistent with the conclusions of Newhouse (1992) and Fonseca et al. (2013), the primary determinant of life expectancy appears to be health investment productivity.

4.3 Sensitivity Analysis

In this section I briefly test the sensitivity of the model to changes to σ by replicating the growth rate and welfare analysis from Section 3.6 for each of the three endogenous mortality specifications. Table 4.2 presents the results for each of the five policy scenarios. Generally, the model does not appear to be sensitive to changes to σ. In most cases, neither the sign nor the magnitude of the change appears to be significantly altered from the exogenous case. Most importantly, there does not appear to be many large swings in life expectancy or the growth rate.

The one exception appears to be changes to government investment. Household consumption and time allocation are consistent across σ. However, the magnitude of the effect of the increase of government investment on the growth rate increases with σ. The increase to both the growth rate and the interest rate has a positive effect on the growth rate of medical consumption, causing life expectancy to increase in the endogenous mortality cases. Moreover, the effect on life expectancy is magnified when I increase σ, so that the largest gains in life expectancy occur when $\sigma = 0.5$ (0.478 percent or 3 months at age 20 and 0.907 percent or just under 2 months at age 65). The gains to life expectancy causes the medical consumption of the elderly to rise, so that M^g/Y actually increases for $\sigma = 0.5$. Finally, the change to the utility multiplier is actually negative when $\sigma = \{0.2, 0.5\}$. This is likely the result of the decline in life expectancy relative to the exogenous case.

Table 4.2 further reinforces the limited role of medical consumption in determining longevity. The large shift in M/Y that occurs when either κ_p or κ_g increase by one percent has a negligible effect on life expectancy. In fact, the largest response of life expectancy (3 additional months) occurs when medical consumption decreases and requires an increase in the growth rate of over 1.8 percent and a large elasticity of survival with respect to medical consumption.

4.4 Conclusions

Until recently, macroeconomic investigations of health insurance were virtually non-existent, despite the widespread concerns over the potential aggregate implications of the rapid growth of medical expenditures and market failures in health insurance markets. However, the uncertainty surrounding the macroeconomic consequences of the ACA has generated considerable interest in macroeconomic analysis of the health care sector. As a result, over the past several years there have been numerous studies utilizing a macroeconomic framework in order to investigate how the structure of the health care sector and health care reform influence various aspects of the economy, such as the growth of medical expenditures, labor supply, welfare, etc.

Unfortunately, these studies have largely focused on steady-state analysis of aggregate welfare or medical expenditure growth. Consequently, the literature still has very little to say conclusively about the relationship between medical expenditures, health care reform and economic growth. Therefore, utilizing the continuous time OLG model with exogenous mortality developed in Chapter 3, I examine how health care reform and fiscal policy influence health investment and time allocation, subsequently leading to changes to output growth and aggregate welfare. Then, in Chapter 4 I relax the exogenous mortality assumption, making the survival probability a function of medical consumption. Using the endogenous mortality model, I test the robustness of the model to changes to health investment productivity and the elasticity of survival with respect to medical consumption.

The exogenous mortality model is calibrated to match US data from 2006-2013 and five policy scenarios are considered. The first two scenarios consider the impact of a health care reform that theoretically results in a one percent increase in the share of privately and publicly-financed health care expenditures respectively. In both cases the fraction of health care financed out-of-pocket is lower than in the benchmark economy. As a result, households in the counterfactual economy will devote a greater portion of income to medical consumption and a smaller fraction to non-medical consumption. Aggregate savings are lower in the counterfactual economy, causing the growth rate of output to be below that of the benchmark economy. Additionally, the utility multiplier will also be lower in the counterfactual economy, in part because of the lower growth rate, and in part because of diminished non-medical consumption and leisure time. Consequently, these two hypothetical health care reforms are welfare reducing in both the short-run and long-run.

In the third and fourth scenarios, I assume that the government has opted to increase public infrastructure investment and consumption. In each case the rise in government expenditures causes the labor income tax rate to rise. Households respond by increasing their savings so that C/Y and M/Y fall proportionately. Increasing the government consumption-output ratio has a negative effect on the growth rate, causing it to fall despite the small increase in household savings. However, increasing government investment has the opposite effect on the growth rate. This outcome is the result of the productivity externality x_t that exists in the firms' production technology defined in equation (3.30). This externality arises from the interaction between the government infrastructure spending and the capital-labor ratio, resulting in constant returns to capital. Additionally, total factor productivity becomes a function of government investment. Consequently, increased government investment increases productivity and induces greater savings, raising the growth rate.

Inevitably, cuts to discretionary government spending will need to occur over the next several decades as health care takes over an ever-increasing share of the government's budget. From my analysis, reducing infrastructure spending will have a dramatic effect on the economy, reducing growth and utility. Conversely, cuts to government consumption may actually have positive benefits in the long-run, raising the growth rate and allowing the marginal effective tax rate to remain low.

The final scenario considers the aggregate impact of raising the Medicare eligibility age from 65 to 67. Government medical consumption-output in the counterfactual economy declines by just under 3.75 percent relative to the benchmark economy, causing the labor income tax rate to fall by nearly one percent. Household savings decline, causing both C/Y and M/Y to increase. As a result, the growth rate falls by 0.635 percent and the average labor supply per worker increases by 0.246 percent. Declining leisure time and output growth reduce the utility multiplier despite the increase in consumption that occurs.

Relaxing the exogenous mortality assumption does not substantially alter the predictions of the model. With the exception of life expectancy, the equilibrium results from the exogenous and endogenous mortality models are nearly identical. Raising the elasticity of survival with respect to medical consumption (σ) must coincide with a reduction of the health investment productivity parameter (ρ) to guarantee that the survival probability declines with age. As a result, life expectancy declines with σ. The version with $\sigma = 0.05$ most closely resembles the observed life expectancy at ages 20 and 65, implying that medical consumption has a minor, positive effect on longevity. The remainder of longevity can be explained by the current level of medical care productivity.

4.5 Final Comments

This section concludes my thesis with a summary of the main findings from the Neoclassical and OLG models. Then, based on these conclusions, I detail several policy recommendations.

4.5.1 Neoclassical Model

1. The largest welfare gains arise from an increase to final goods productivity, which has an immediate and positive effect on output. This allows aggregate consumption of both medical and non-medical goods and services to rise, while leaving steady-state savings and time allocation unaffected.

2. Increasing health investment productivity has an identical, albeit smaller, effect on the economy. A positive health investment productivity shock will cause the health capital stock to rise. However, due to diminishing returns to health capital in the production function, the subsequent rise in aggregate output will been substantially smaller than the rise that occurs in response to a positive productivity shock in the final goods sector.

3. An exogenous rise in the depreciation rate reduces steady-state health capital, leading to a decline in output and physical capital. Aggregate consumption of both health care and non-medical goods and services[2] fall and the household devotes more time to health maintenance, leading to a decline in both labor and leisure time. Declining medical and non-medical consumption, health capital, and leisure time causes aggregate welfare to fall.

[2] c/y falls while m/y rises

4. Reducing the out-of-pocket cost of health care prompts the household to increase its consumption of health care and reduce its non-medical consumption. Health capital accumulates, raising steady-state output, physical capital, and labor time. Both leisure and health maintenance time fall slightly. Aggregate welfare declines despite increased medical consumption and health capital due to the fall in non-medical consumption.

4.5.2 OLG Model

1. Decreasing the out-of-pocket cost of health care causes households to reduce their non-medical consumption in favor of increased medical consumption, so that M/Y rises and C/Y falls. The aggregate consumption-capital ratio rises, thereby reducing output growth. The labor income tax rate rises to accommodate the increase in public health care expenditures. The aggregate labor supply rises, reducing leisure time. Declining leisure time and non-medical consumption reduces the utility multiplier, which combined with the decline in the economic growth rate, implies that aggregate welfare will decline in the long-run.

2. Increasing the rate of government investment raises productivity, translating to greater output growth, and welfare. Conversely, increasing the government consumption-output ratio has no effect on productivity, causing output growth and welfare to fall.

3. When actuarially fair life annuities are present in the model, raising the Medicare eligibility age to 67 will lead to significant reductions to Medicare expenditures and is a useful tool for reducing public health care spending. The labor income tax rate falls by nearly one percent, prompting households to increase their labor time. Both M/Y and C/Y rise slightly, causing the economic growth rate to decline. This, combined with the reduction in leisure time, causes the utility multiplier to fall, implying that households are worse-off.

4. The out-of-pocket price elasticity of medical consumption implied by the model is approximately -0.83, significantly higher than the Manning et al. (1987) estimate. However, this elasticity appears to be within the range of elasticity estimates in the literature (see Borger et al. [2008]).

5. Medical consumption has a small, positive effect on longevity, with an elasticity with respect to survival of 0.05. Health investment productivity appears to be the primary determinant of longevity.

4.5.3 Policy Recommendations

Both models emphasize the importance of productivity and output in determining aggregate welfare. In the Neoclassical model, a one percent rise in final goods productivity leads to substantial welfare gains. Likewise, in the OLG model, final goods productivity has a positive effect on economic growth, a major determinant of long-run aggregate welfare (see equation (3.40a)). Similarly, in the Neoclassical model I found that health investment productivity is positively correlated with output and aggregate welfare. Moreover, the endogenous mortality OLG model suggests that health investment productivity is the primary determinant of life expectancy.

Therefore, I conclude that both final goods and health investment productivity have a significant impact on aggregate welfare growth. Additional research into the relationship between the aggregate demand for medical care, health insurance, health investment productivity growth, and long-run endogenous growth may lend valuable insight into the long-run consequences of medical expenditure growth and health care reform.

The US spends considerably more per capita on health care than any other nation and is arguably the worldwide leader in medical innovation. Yet, life expectancy in the US is lower than in many other developed nations. If health investment productivity is the main determining factor of life expectancy, with medical consumption having only a small role, then it is possible that the US has lower average health investment productivity than other developed nations, leading to lower life expectancies. Health investment productivity is determined by many factors including the current level of medical technology, public health initiatives, the riskiness of individuals, and access to quality health care. So, while the US is at the forefront of medical technology advancement, it is possible that individuals in the US may engage in riskier behavior[3] and that the prevalence of uninsured households may limit access to first class health care for millions of households, resulting in an average health investment productivity that is below that of other OECD nations.

Another parallel between the two models is the relationship between the equilibrium out-of-pocket cost of health care and aggregate welfare. In both models, households increase medical consumption and labor time, and decrease non-medical consumption and leisure time when the out-of-pocket cost of health care declines. Health maintenance time also falls in the Neoclassical model, raising the rate of health capital depreciation. In the OLG model, economic growth declines as the rise in medical consumption causes the savings rate to fall. Consequently, reforms that increase public and private health insurance coverage may reduce long-run economic growth and unintentionally create a disincentive to undertake preventative measures (i.e. health maintenance), thereby increasing the mortality rate.

These two unintended consequences contend with the welfare gains that arise from the expansion of health insurance coverage,[4] so that the long-run aggregate welfare consequences are ambiguous. In order to ensure that health care reform does not cause aggregate welfare to diminish, policymakers must make certain that the new policies do not adversely affect aggregate producutivity, health investment productivity, and economic growth. From my

[3] e.g. 28.6 percent of the total population in the US is obese versus the OECD average of 15.4 percent.

[4] Pashchenko and Porapakkarm (2013) utilize a general equilibrium life cycle model to analyze the effect of the ACA on welfare and find that there are gains from the resulting reduction in the number of uninsured individuals and increased wealth redistribution.

analysis, this can be achieved by reducing the generosity of public insurance, maintaining optimal levels of government investment, and creating new incentives for the generation of new medical technologies.

Reducing the generosity of private health insurance policies should also be a priority. This can be accomplished by eliminating the employer-provided health insurance tax exemption, providing households with greater choice in plans (i.e. high deductible plans, catastrophic-only coverage, HSAs, etc.), and removing excessive minimum coverage requirements would all put downward pressure on the private health insurance share of medical expenditures, having a positive effect on economic growth and aggregate welfare.

Table 4.2: Percent Change of Balanced Growth Path Variables (Endogenous Mortality)

	C/Y	M/Y	M^p/Y	M^g/Y	Π/Y	L	$1-L$	τ_w	$LE20$	$LE65$	g^*	$\tilde{u}$
κ_p												
$\sigma = 0,\ \rho = .0566$	-0.590	2.587	2.571	2.613	3.596	0.251	-0.104	0.670	0.000	0.000	-0.266	-0.184
$\sigma = .05,\ \rho = .05$	-0.590	2.587	2.571	2.613	3.597	0.251	-0.104	0.669	-0.002	-0.004	-0.268	-0.182
$\sigma = .2,\ \rho = .024$	-0.589	2.588	2.574	2.613	3.599	0.256	-0.104	0.654	-0.009	-0.017	-0.298	-0.179
$\sigma = .5,\ \rho = .003$	-0.588	2.589	2.577	2.610	3.602	0.258	-0.104	0.647	-0.024	-0.044	-0.312	-0.169
κ_g												
$\sigma = 0,\ \rho = .0566$	-0.243	1.079	0.432	2.104	1.070	0.035	-0.015	0.540	0.000	0.000	-0.151	-0.083
$\sigma = .05,\ \rho = .05$	-0.243	1.079	0.434	2.104	1.070	0.035	-0.015	0.539	-0.001	-0.002	-0.152	-0.082
$\sigma = .2,\ \rho = .024$	-0.243	1.079	0.468	2.103	1.071	0.039	-0.016	0.526	-0.005	-0.009	-0.162	-0.079
$\sigma = .5,\ \rho = .003$	-0.243	1.079	0.482	2.101	1.073	0.041	-0.017	0.521	-0.013	-0.023	-0.167	-0.074
ν												
$\sigma = 0,\ \rho = .0566$	-0.106	-0.106	-0.140	-0.053	-0.140	0.004	-0.002	0.190	0.000	0.000	1.718	0.060
$\sigma = .05,\ \rho = .05$	-0.106	-0.106	-0.149	-0.039	-0.149	0.008	-0.003	0.194	0.050	0.090	1.731	0.027
$\sigma = .2,\ \rho = .024$	-0.108	-0.108	-0.172	-0.001	-0.172	0.016	-0.006	0.205	0.192	0.360	1.802	-0.072
$\sigma = .5,\ \rho = .003$	-0.111	-0.111	-0.222	0.079	-0.222	0.034	-0.014	0.225	0.478	0.907	1.873	-0.263
η												
$\sigma = 0,\ \rho = .0566$	-0.198	-0.198	-0.201	-0.192	-0.201	-0.029	0.012	0.650	0.000	0.000	-0.057	-0.068
$\sigma = .05,\ \rho = .05$	-0.198	-0.198	-0.201	-0.192	-0.201	-0.029	0.012	0.650	0.000	-0.001	-0.057	-0.067
$\sigma = .2,\ \rho = .024$	-0.197	-0.197	-0.200	-0.192	-0.200	-0.030	0.012	0.657	-0.002	-0.003	-0.061	-0.066
$\sigma = .5,\ \rho = .003$	-0.197	-0.197	-0.199	-0.193	-0.199	-0.030	0.012	0.659	-0.005	-0.009	-0.063	-0.064
zm												
$\sigma = 0,\ \rho = .0566$	0.034	0.034	2.404	-3.721	2.418	0.246	-0.102	-0.954	0.000	0.000	-0.635	-0.112
$\sigma = .05,\ \rho = .05$	0.034	0.034	2.412	-3.744	2.426	0.246	-0.102	-0.959	-0.005	-0.009	-0.638	-0.108
$\sigma = .2,\ \rho = .024$	0.034	0.034	2.290	-3.749	2.303	0.236	-0.096	-0.938	-0.020	-0.037	-0.647	-0.092
$\sigma = .5,\ \rho = .003$	0.034	0.034	2.237	-3.739	2.250	0.230	-0.093	-0.927	-0.049	-0.091	-0.651	-0.069

* 20-year average annual growth rate of real GDP per capita (1994-2013).

Appendix A

Appendix

A.1 Linearization

The core dynamics for the Neoclassical model are defined by the following four equations:

$$\dot{k} = (1-g)y - c_p - (1-a)(\nu m^{\nu-1})m - \delta_k k \tag{A.1a}$$

$$\dot{h} = Bm^{\psi}u^{1-\psi} - [\delta_h + \rho(u)]h \tag{A.1b}$$

$$\dot{\lambda_1} = \left[\delta_k + \beta - \alpha(1-\tau_k)Ah^{\eta}\left(\frac{k}{1-u-l}\right)^{\alpha-1}\right]\lambda_1 \tag{A.1c}$$

$$\dot{\lambda_2} = [\delta_h + \rho(u) + \beta]\lambda_2 - \theta_h h^{\gamma\theta_h - 1}[c_p^{\theta_c} m^{1-\theta_c} l^{\theta_l}]^{\gamma} \tag{A.1d}$$

To solve for the steady-state variables, I first must first solve for $\{c_p, m, l, u\}$ in terms of the state and costate variables $\{k, h, \lambda_1, \lambda_2\}$. Then, I can solve for $\{k, h, \lambda_1, \lambda_2\}$ analytically and then substitute these values into the equations for $\{c_p, m, l, u\}$. In order to obtain the eigenvalues for the system I totally differentiate (A.la)-(A.1d) with respect to $\{k, h, \lambda_1, \lambda_2\}$.[1]

[1]Note that $\{c_p, m, l, u\}$ are functions of $\{k, h, \lambda_1, \lambda_2\}$

The total differentiation is given as:

$$\begin{bmatrix} \dot{k} \\ \dot{h} \\ \dot{\lambda_1} \\ \dot{\lambda_2} \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \\ a_{41} & a_{42} & a_{43} & a_{44} \end{bmatrix} \times \begin{bmatrix} k - \tilde{k} \\ h - \tilde{h} \\ \lambda_1 - \tilde{\lambda_1} \\ \lambda_2 - \tilde{\lambda_2} \end{bmatrix} \tag{A.2}$$

where

$$a_{11} = (1-g)\frac{\partial y}{\partial k} - \delta_k - \frac{\partial c_p}{\partial k} - (1-a)\left[\frac{\partial P_m}{\partial m}m + P_m\right]\frac{\partial m}{\partial k} + (1-g)\frac{\partial y}{\partial l}\frac{\partial l}{\partial k} + (1-g)\frac{\partial y}{\partial u}\frac{\partial u}{\partial k} \tag{A.2a}$$

$$a_{12} = (1-g)\frac{\partial y}{\partial h} - \frac{\partial c_p}{\partial h} - (1-a)\left[\frac{\partial P_m}{\partial m}m + P_m\right]\frac{\partial m}{\partial h} + (1-g)\frac{\partial y}{\partial l}\frac{\partial l}{\partial h} + (1-g)\frac{\partial y}{\partial u}\frac{\partial u}{\partial h} \tag{A.2b}$$

$$a_{13} = -\frac{\partial c_p}{\partial \lambda_1} - (1-a)\left[\frac{\partial P_m}{\partial m}m + P_m\right]\frac{\partial m}{\partial \lambda_1} + (1-g)\frac{\partial y}{\partial l}\frac{\partial l}{\partial \lambda_1} + (1-g)\frac{\partial y}{\partial u}\frac{\partial u}{\partial \lambda_1} \tag{A.2c}$$

$$a_{14} = -\frac{\partial c_p}{\partial \lambda_2} - (1-a)\left[\frac{\partial P_m}{\partial m}m + P_m\right]\frac{\partial m}{\partial \lambda_2} + (1-g)\frac{\partial y}{\partial l}\frac{\partial l}{\partial \lambda_2} + (1-g)\frac{\partial y}{\partial u}\frac{\partial u}{\partial \lambda_2} \tag{A.2d}$$

$$a_{21} = \left[\frac{\partial F(m,u)}{\partial m}\right]\left[\frac{\partial m}{\partial k}\right] + \left[\frac{\partial F(m,u)}{\partial u} - \left(\frac{\partial \rho(u)}{\partial u}\right)h\right]\frac{\partial u}{\partial k} \tag{A.2e}$$

$$a_{22} = \left[\frac{\partial F(m,u)}{\partial m}\right]\left[\frac{\partial m}{\partial h}\right] + \left[\frac{\partial F(m,u)}{\partial u} - \left(\frac{\partial \rho(u)}{\partial u}\right)h\right]\frac{\partial u}{\partial h} - [\delta_h + \rho(u)] \tag{A.2f}$$

$$a_{23} = \left[\frac{\partial F(m,u)}{\partial m}\right]\left[\frac{\partial m}{\partial \lambda_1}\right] + \left[\frac{\partial F(m,u)}{\partial u} - \left(\frac{\partial \rho(u)}{\partial u}\right)h\right]\frac{\partial u}{\partial \lambda_1} \tag{A.2g}$$

$$a_{24} = \left[\frac{\partial F(m,u)}{\partial m}\right]\left[\frac{\partial m}{\partial \lambda_2}\right] + \left[\frac{\partial F(m,u)}{\partial u} - \left(\frac{\partial \rho(u)}{\partial u}\right)h\right]\frac{\partial u}{\partial \lambda_2} \tag{A.2h}$$

$$a_{31} = -\lambda_1(1-\tau_k)\left[\frac{\partial r}{\partial k} + \left(\frac{\partial r}{\partial l}\right)\left(\frac{\partial l}{\partial k}\right) + \left(\frac{\partial r}{\partial u}\right)\left(\frac{\partial u}{\partial k}\right)\right] \tag{A.2i}$$

$$a_{32} = -\lambda_1(1-\tau_k)\left[\frac{\partial r}{\partial h} + \left(\frac{\partial r}{\partial l}\right)\left(\frac{\partial l}{\partial h}\right) + \left(\frac{\partial r}{\partial u}\right)\left(\frac{\partial u}{\partial h}\right)\right] \tag{A.2j}$$

$$a_{33} = \delta_k + \beta - (1-\tau_k)r - \lambda_1(1-\tau_k)\left[\left(\frac{\partial r}{\partial l}\right)\left(\frac{\partial l}{\partial \lambda_1}\right) + \left(\frac{\partial r}{\partial u}\right)\left(\frac{\partial u}{\partial \lambda_1}\right)\right] \tag{A.2k}$$

$$a_{34} = -\lambda_1(1-\tau_k)\left[\left(\frac{\partial r}{\partial l}\right)\left(\frac{\partial l}{\partial \lambda_2}\right) + \left(\frac{\partial r}{\partial u}\right)\left(\frac{\partial u}{\partial \lambda_2}\right)\right] \tag{A.2l}$$

$$a_{41} = -\frac{\partial^2 U}{\partial h \partial c_p}\frac{\partial c_p}{\partial k} - \frac{\partial^2 U}{\partial h \partial m}\frac{\partial m}{\partial k} - \frac{\partial^2 U}{\partial h \partial l}\frac{\partial l}{\partial k} + \lambda_2\left[\frac{\partial \rho(u)}{\partial u}\right]\frac{\partial u}{\partial k} \tag{A.2m}$$

$$a_{42} = -\frac{\partial^2 U}{\partial h^2} - \frac{\partial^2 U}{\partial h \partial c_p}\frac{\partial c_p}{\partial h} - \frac{\partial^2 U}{\partial h \partial m}\frac{\partial m}{\partial h} - \frac{\partial^2 U}{\partial h \partial l}\frac{\partial l}{\partial h} + \lambda_2\left[\frac{\partial \rho(u)}{\partial u}\right]\frac{\partial u}{\partial h} \tag{A.2n}$$

$$a_{43} = -\frac{\partial^2 U}{\partial h \partial c_p}\frac{\partial c_p}{\partial \lambda_1} - \frac{\partial^2 U}{\partial h \partial m}\frac{\partial m}{\partial \lambda_1} - \frac{\partial^2 U}{\partial h \partial l}\frac{\partial l}{\partial \lambda_1} + \lambda_2\left[\frac{\partial \rho(u)}{\partial u}\right]\frac{\partial u}{\partial \lambda_1} \tag{A.2o}$$

$$a_{44} = \delta_h + \rho(u) + \beta - \frac{\partial^2 U}{\partial h \partial c_p}\frac{\partial c_p}{\partial \lambda_2} - \frac{\partial^2 U}{\partial h \partial m}\frac{\partial m}{\partial \lambda_2} - \frac{\partial^2 U}{\partial h \partial l}\frac{\partial l}{\partial \lambda_2} + \lambda_2\left[\frac{\partial \rho(u)}{\partial u}\right]\frac{\partial u}{\partial \lambda_2} \tag{A.2p}$$

In order to solve this linear system I need to solve for the partial derivative of $\{c_p, m, l, u\}$ with respect to $\{k, h, \lambda_1, \lambda_2\}$. I begin by totally differentiating equations (10a)-(10d). Then apply Cramer's rule as follows:

$$\begin{bmatrix} U_{cc} & U_{cm} & U_{cl} & 0 \\ U_{mc} & b_{22} & U_{ml} & F_{mu}\lambda_2 \\ U_{lc} & b_{32} & b_{33} & b_{34} \\ 0 & b_{42} & b_{43} & b_{44} \end{bmatrix} \times \begin{bmatrix} dc_p \\ dm \\ dl \\ du \end{bmatrix} \tag{A.3}$$

$$= \begin{bmatrix} -U_{ch}dh + d\lambda_1 \\ -U_{mh}dh + (b-a)P_m d\lambda_1 - F_m d\lambda_2 \\ \lambda_1(1-\tau_w)\frac{\partial y_e}{\partial k}dk + \left[\lambda_1(1-\tau_w)\frac{\partial y_e}{\partial h} - U_{lh}\right]dh + (1-\tau_w)w d\lambda_1 \\ \lambda_1(1-\tau_w)\frac{\partial y_e}{\partial k}dk + \lambda_1(1-\tau_w)\frac{\partial y_e}{\partial h}dh + (1-\tau_w)w d\lambda_1 - F_u d\lambda_2 \end{bmatrix}$$

where

$$b_{22} = U_{mm} + F_{mm}\lambda_2 - (b-a)\frac{\partial P_m}{\partial m}\lambda_1$$

$$b_{32} = U_{lm} + \lambda_1(1-\tau_w)\frac{\partial w}{\partial m}$$

$$b_{33} = U_{ll} - \lambda_1(1-\tau_w)\frac{\partial w}{\partial l}$$

$$b_{34} = -\lambda_1(1-\tau_w)\frac{\partial w}{\partial u}$$

$$b_{42} = F_{um}\lambda_2 - \lambda_1(1-\tau_w)\frac{\partial \pi}{\partial m}$$

$$b_{43} = -\lambda_1(1-\tau_w)\frac{\partial w}{\partial l}$$

$$b_{44} = F_{uu}\lambda_2 - \lambda_1(1-\tau_w)\frac{\partial w}{\partial u}$$

Solving for this system of equations gives the partial derivatives of $\{c_p, m, l, u\}$ with respect to $\{k, h, \lambda_1, \lambda_2\}$. Substituting these values into equations (A.2a)-(A.2p) completes the linearization.

A.2 Tables and Figures

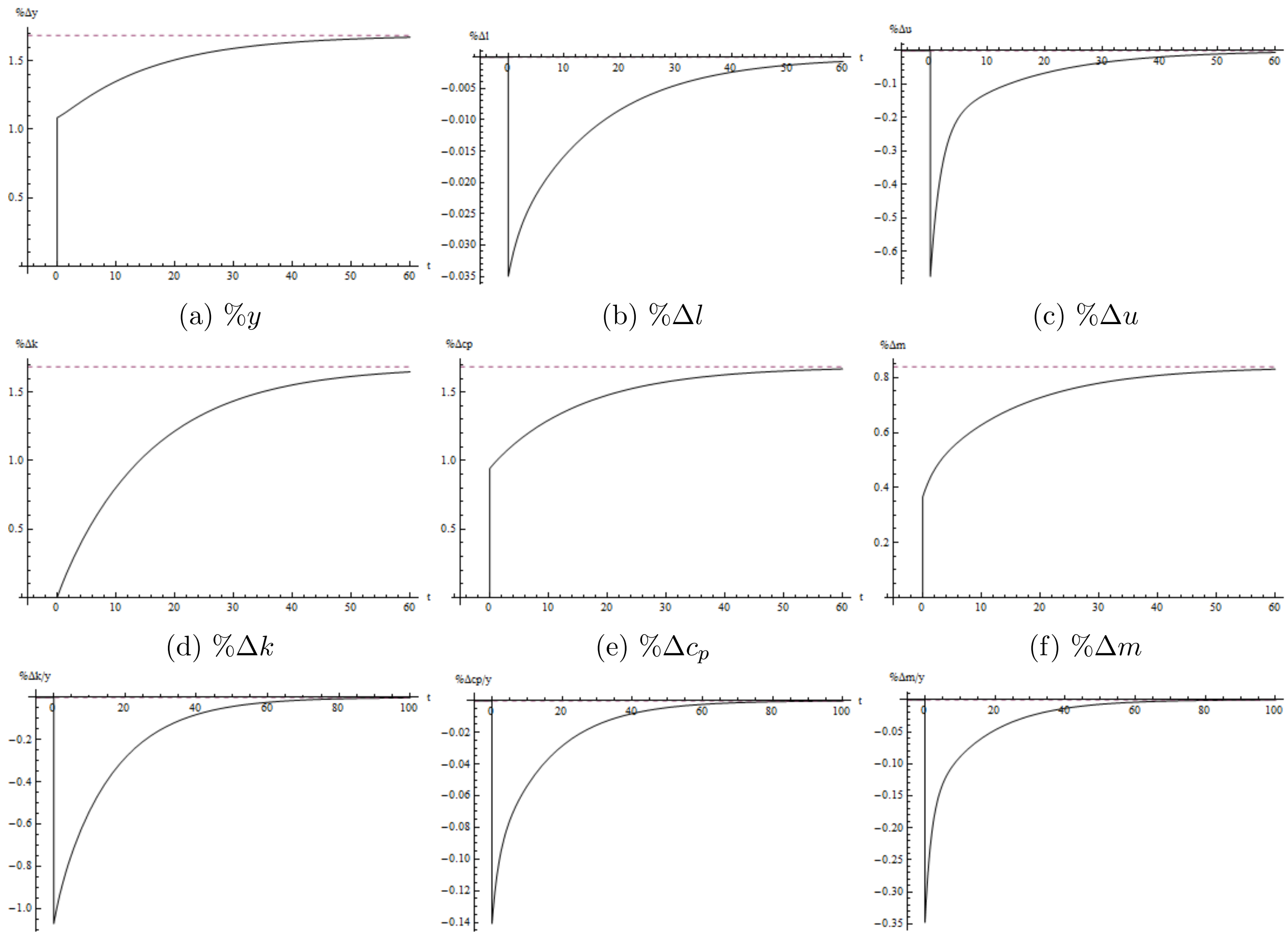
This section contains a table and the transitional dynamics from the Neoclassical model. The table is presented first, then the figures are presented in the order that they are referenced in the text.

Table A.1: Expenditure Thresholds (2009 Dollars)

Year	Threshold	ρ	Year	Threshold	ρ
1996	\$3,936.32	0.133	2004	\$4,315.61	0.183
1997	\$3,662.87	0.138	2005	\$4,225.59	0.185
1998	\$3,708.91	0.144	2006	\$4,293.03	0.190
1999	\$3,922.55	0.143	2007	\$4,535.87	0.186
2000	\$,3675.03	0.144	2008	\$4,083.76	0.176
2001	\$3,956.69	0.167	2009	\$4,640.00	0.179
2002	\$4,346.11	0.174	2010	\$4,494.65	0.168
2003	\$4,335.33	0.177	2011	\$4,473.28	0.166
Ave	\$4,162.85	0.166			

Table A.2: Chapter 3: Parameters

Parameter	Value	Description; [Source]
γ	-1	Determines IES of c (IES=0.5); [Ogaki & Reinhart (1998) & Guvenen (2006)]
β	0.03	Rate of time preference
θ_c	0.275	Preference parameter for non-medical consumption
θ_m	0.012	Preference parameter for medical consumption
θ_l	0.713	Preference parameter for leisure time
A	0.429	Total factor productivity of final goods production;
α	0.3	Share of income due to capital; [Literature standard]
δ	0.05	Depreciation rate of capital; [Literature standard]
r	0.0787	Before-tax Interest rate; [Bruce & Turnovsky (2013)]
τ_k	0.15	Tax rate on capital income; [Chatterjee, Guiliano, & Turnovsky (2004)]
ρ	0.0566	Survival rate parameter (Exogenous Mortality); [Bruce & Turnovsky (2013)]
ν	0.036	Fraction of gross output devoted to government infrastructure investment; [NIPA]
η	0.150	Fraction of net output devoted to government consumption; [NIPA]
$\kappa_p(z < zm)$	0.573	Share of health care financed by private insurance when young (Age$<$65); [MEPS]
$\kappa_p(z \geq zm)$	0.175	Share of health care financed by private insurance when old (Age$\geq$65); [MEPS]
$\kappa_g(z < zm)$	0.242	Share of health care financed by government when young (Age$<$65); [MEPS]
$\kappa_g(z \geq zm)$	0.766	Share of health care financed by government when old (Age$\geq$65); [MEPS]
n	0.008	Population growth rate; World Bank
ω	75	Maximum attainable age (95 years old); [Bruce and Turnovsky (2013)]
zm	45	Age of eligibility for Medicare (65 years old)
ℓ	58	Age of mandatory retirement (78 years old); [Bruce & Turnovsky (2013)]

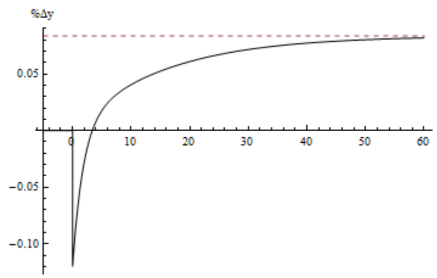


(a) $\%y$ (b) $\%\Delta l$ (c) $\%\Delta u$

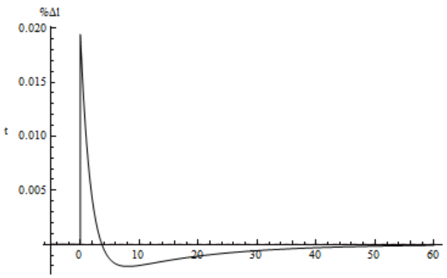
(d) $\%\Delta k$ (e) $\%\Delta c_p$ (f) $\%\Delta m$

(g) $\%\Delta(k/y)$ (h) $\%\Delta(c_p/y)$ (i) $\%\Delta(P_m m/y)$

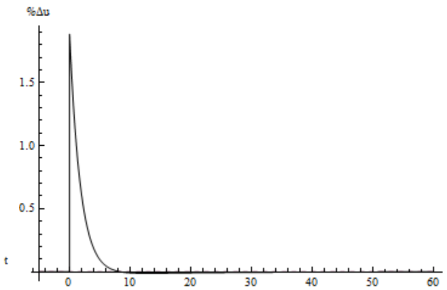
Figure A.1: Time Paths - 1% Rise in Final Goods Productivity



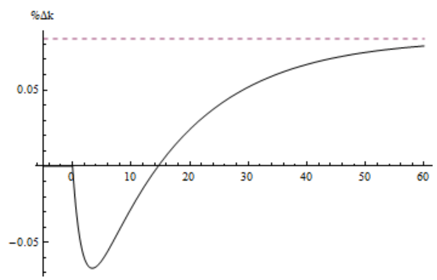
(a) $\%\Delta y$



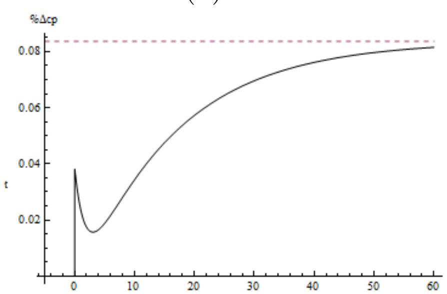
(b) $\%\Delta l$



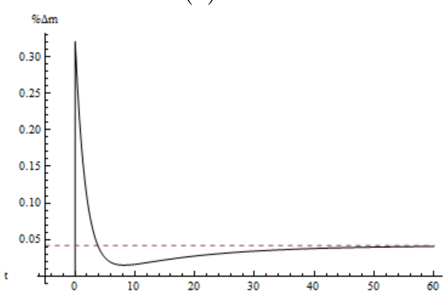
(c) $\%\Delta u$



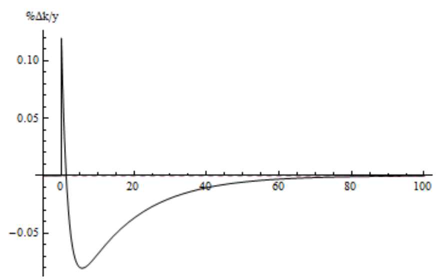
(d) $\%\Delta k$



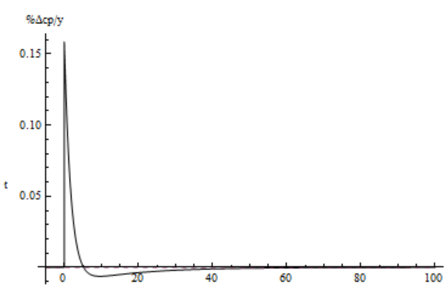
(e) $\%\Delta c_p$



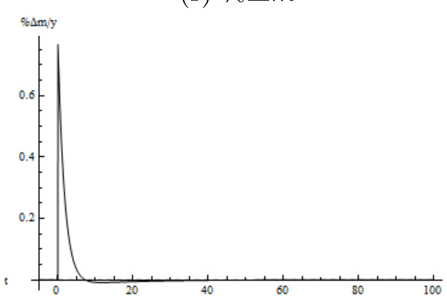
(f) $\%\Delta m$



(g) $\%\Delta(k/y)$

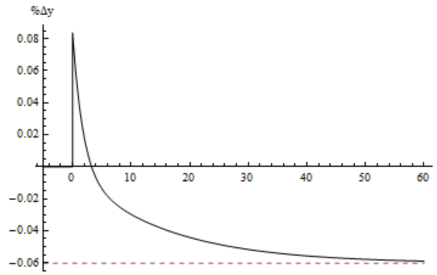


(h) $\%\Delta(c_p/y)$

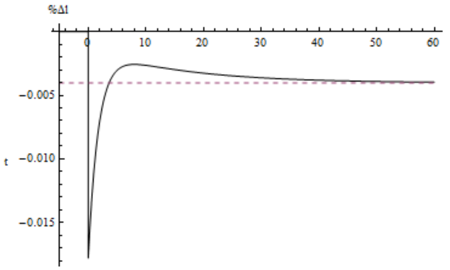


(i) $\%\Delta(P_m m/y)$

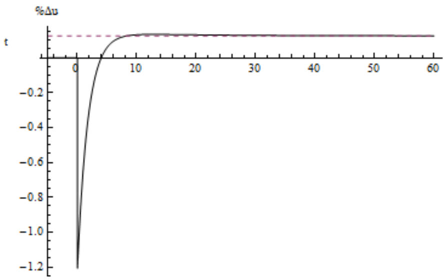
Figure A.2: Time Paths - 1% Rise in Health Investment Productivity



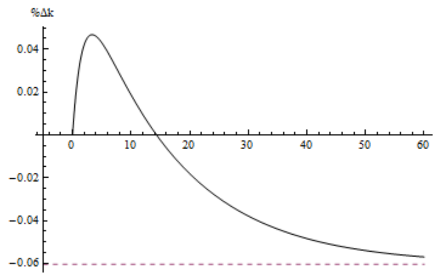
(a) $\%\Delta y$



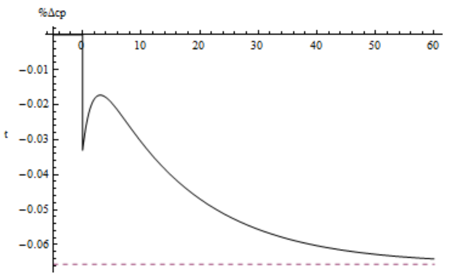
(b) $\%\Delta l$



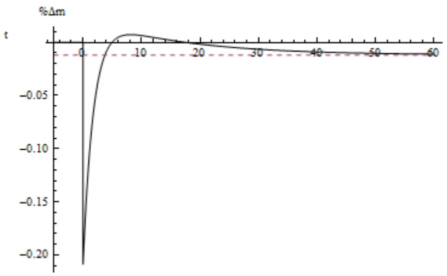
(c) $\%\Delta u$



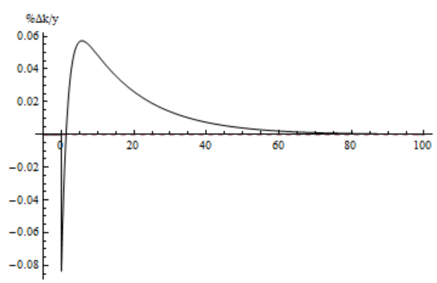
(d) $\%\Delta k$



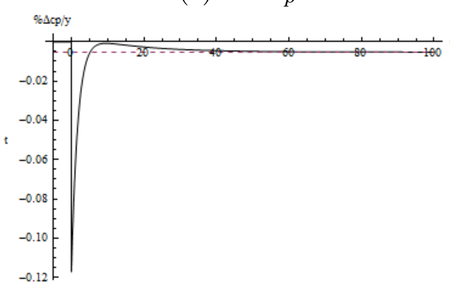
(e) $\%\Delta c_p$



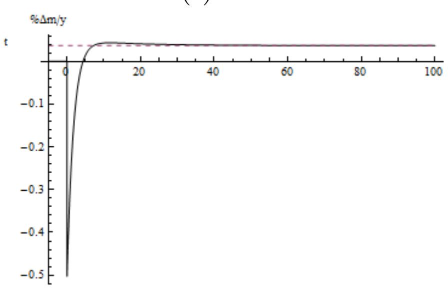
(f) $\%\Delta m$



(g) $\%\Delta(k/y)$

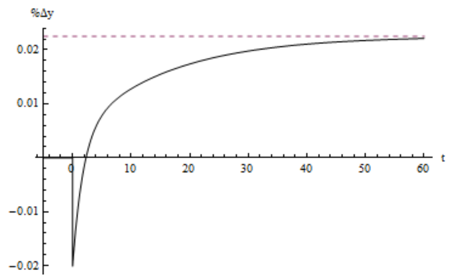


(h) $\%\Delta(c_p/y)$

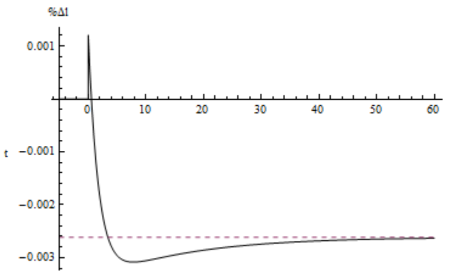


(i) $\%\Delta(P_m m/y)$

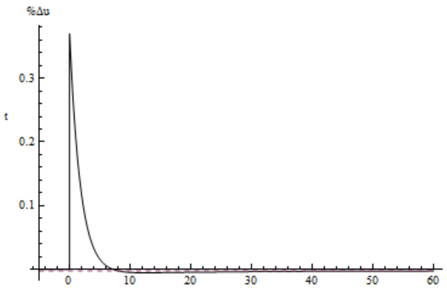
Figure A.3: Time Paths - 1% Rise in the Depreciation Rate of Health



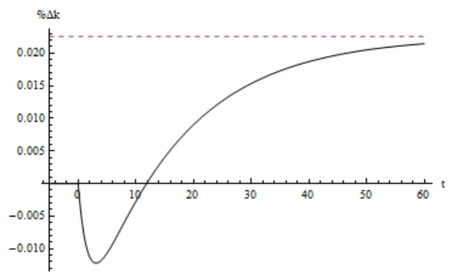
(a) $\%\Delta y$



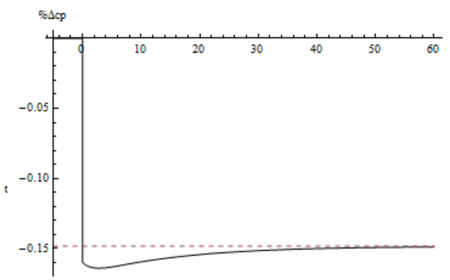
(b) $\%\Delta l$



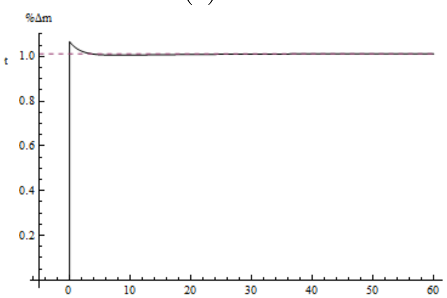
(c) $\%\Delta u$



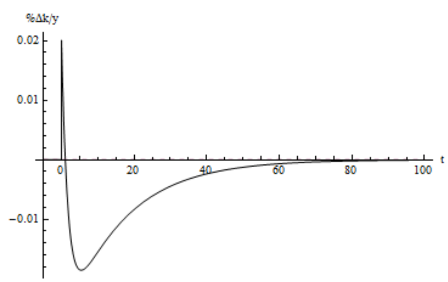
(d) $\%\Delta k$



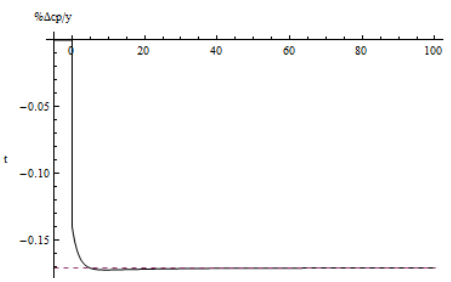
(e) $\%\Delta c_p$



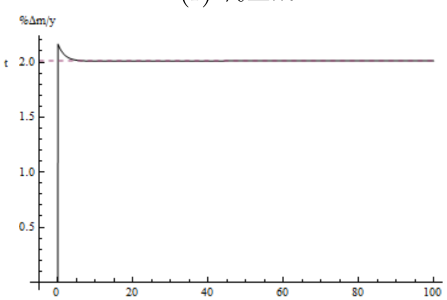
(f) $\%\Delta m$



(g) $\%\Delta(k/y)$

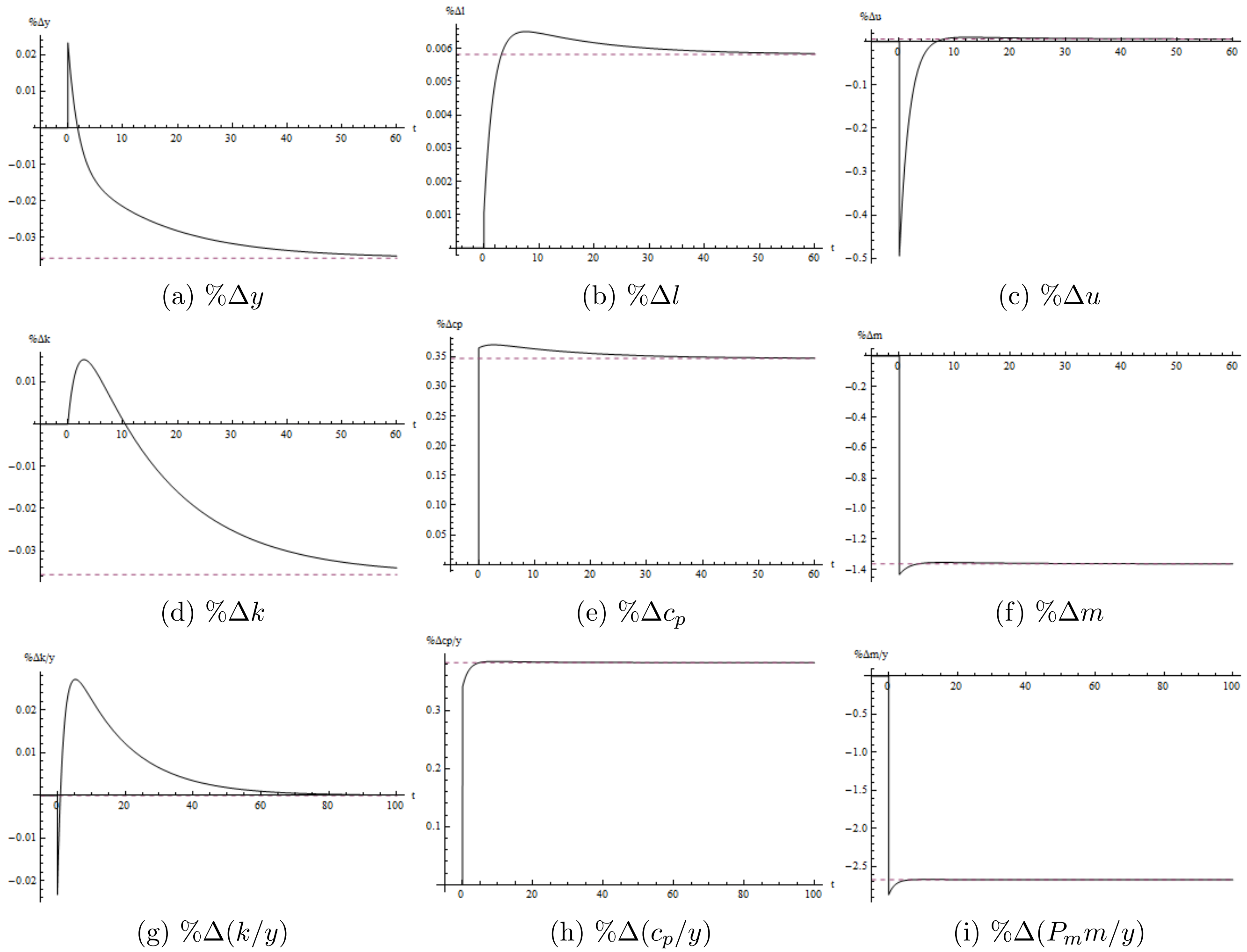


(h) $\%\Delta(c_p/y)$



(i) $\%\Delta(P_m m/y)$

Figure A.4: Time Paths - 1% Rise in Public Subsidy Rate



(a) $\%\Delta y$ (b) $\%\Delta l$ (c) $\%\Delta u$

(d) $\%\Delta k$ (e) $\%\Delta c_p$ (f) $\%\Delta m$

(g) $\%\Delta(k/y)$ (h) $\%\Delta(c_p/y)$ (i) $\%\Delta(P_m m/y)$

Figure A.5: Time Paths - 1% Rise in Coinsurance Rate

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