Technological Advance and the Growth in Health Care Spending*

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Abstract

Since 1950, the U.S. has experienced a significant expansion in health care spending and longevity. In this paper, we quantify the importance of medical technology improvements and rising incomes in explaining these changes. To achieve this, we develop a dynamic general equilibrium model in which consumers face idiosyncratic uncertainty in health. Both health care spending and life expectancy are endogenously determined. According to our model, medical technology improvements and rising incomes can explain all of the increase in health care spending and more than 60% of the increase in life expectancy at age 25 in the United States between 1950 and 2001.

Keywords: Technological progress, life expectancy, health care spending, health

JEL classification: E13, I12, O11, O33

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1 Introduction

During the second half of the twentieth century, the U.S. has experienced a significant increase in both health care spending and longevity. Between 1950 and 2001, the share of personal medical expenditures in U.S. GDP has increased from 3.7% to 12.2%, while life expectancy at age 25 has extended by 6.8 years. Similar patterns were also observed in other OECD countries over the same time period. This suggests that at least some part of these changes is driven by factors that are common across borders. The past several decades also witnessed an influx of new techniques and technologies (such as open-heart surgery, organ transplants, magnetic resonance imaging, etc.) that revolutionized the practice of medicine. In this paper, we show that the increase in health care spending and longevity in the United States between 1950 and 2001 can be explained by a combination of technological progress in medical treatment and rising incomes.

To address the issue in hand, we adopt a stochastic, multi-period overlapping generations model as the analytical vehicle. At the heart of the analysis is individual's demand for health. Health is formulated as a stock variable, while health care spending is an investment in this stock. At each age, each individual faces two types of uncertainty. First, there is a certain probability of getting sick. Diseases are modelled as exogenous shocks that lower a person's health stock. The effect of the negative health shocks can be reduced by utilizing health care services and transforming them into new units of health. Second, at the end of each age, each individual faces a certain probability of dying. The survival probability is endogenously determined by the person's health. In this study, we assume that health is demanded because it can prolong people's life. Using medical care as input, new units of health is produced via a health production function. The latter captures the current state of the art of medical technology. An improvement in medical technology then takes the form of an increase in the marginal product of medical care. This type of improvement will raise the expenditures on health care for two reasons. First, more effective treatment encourages the demand for medical care. This effect is particularly prominent among the elderly. Second, when lives are saved and extended by the new technologies, additional spending will be incurred during the additional years of life. In other words, total health care spending increases because people live longer.

The same topic has been previously studied by Hall and Jones (2007).[1] There are two major

[1] Other studies that have explored the macroeconomic implications of health care spending and health insurance include Jeske and Kitao (2009) and Zhao (2014) among others.

differences between these two work. First, Hall and Jones conclude that income growth alone can explain the expansion in health care spending. The key assumption behind their argument is that the demand for medical care is more income elastic than that for other goods or services. In the present study, we emphasize the importance of both medical technology improvements and income growth. In particular, in the quantitative analysis we show that income growth alone is not enough to generate the observed increase in health care spending. Another major difference is that Hall and Jones (2007) do not consider any uncertainty in health status or medical spending, and thus there is no role for health insurance. In the present study, the relationship between medical spending and insurance coverage is explicitly considered. Earlier studies such as Pauly (1986) suggest that the growth in health care spending is largely due to the fact that the U.S. population is "overinsured". Their argument is as follows. Traditional insurance that reimburses part of the medical expenses effectively lowers the price of medical care. This induces the insured to spend more on medical services than they would have if they were uninsured. The situation is exacerbated by the fact that employer-provided health insurance is tax-deductible which results in "excessive" purchase of health insurance and hence "excessive" health care spending.

In order to isolate the effects due to the changes in insurance coverage, we compare two model economies with different degrees of insurance opportunity. In the benchmark economy, consumers have access to both public and private health insurance. In the quantitative analysis, we calibrate the benchmark model to match the observed changes in health care spending and insurance coverage in the United States. We then compare this to a hypothetical economy which has experienced the same improvement in medical technology and income growth, but *without any health insurance*. The main findings of this comparison are as follows. First, in the presence of medical technology improvements and rising incomes, a large increase in health care spending can be obtained even if the consumers are cut off from all insurance. Second, technological progress in medical treatment, combined with rising incomes, can explain all the increase in medical spending, and more than 60% of the increase in life expectancy at age 25 in the United States between 1950 and 2001.

The remainder of this paper is structured as follows. Section 2 reviews the trends in medical spending, life expectancy and insurance coverage since 1950. Section 3 presents the model environment. Section 4 explains the calibration procedure. The main findings are reported in Section 5, followed by some concluding remarks in Section 6.

2 History

2.1 Some Facts

Figure 1 illustrates the dramatic increase in real per-capita personal medical expenditures during the twentieth century.[2] In 1950 a typical American spent $448 (in constant 2001 dollars) on medical care. This increased by a factor of 9.7 over the next fifty years and reached $4,361 in 2001.[3] During the same period, real per-capita GDP increased only by a factor of 2.9. The result is a rising share of medical spending in GDP as shown in Figure 2. Over the period 1950-2001 the share of medical spending in GDP increased from 3.7% to 12.2%. From the figure it is obvious that the rising trend began at some point around 1950. This is one of the reasons why this paper focuses on the latter half of the twentieth century.[4] When Medicare and Medicaid were enacted in 1966 the share of medical spending had already increased to 4.9%. Another way to assess the rising importance of health care spending is to consider its share in personal consumption expenditures.[5] In 1950 medical spending accounted for a mere 5.6% of total personal consumption expenditures, much smaller than the shares on food (27.5%) and housing (11.1%). As depicted in Figure 3, this share remained almost constant during the early decades and started gaining momentum only in the 1950s. The share of medical spending had already reached 7.9% by the year 1966. In 2001 the share of medical care in total consumption expenditures was 17.3%, exceeding the share on either food (13.5%) or housing (15.0%). Over the same time period, medical spending has increased for all age groups but at different paces. The increase was particularly prominent among the elderly (those aged 65 or above). Over the period 1950-2000, real per-person spending among the elderly grew at an average annual rate of 5.4%, whereas the corresponding growth

[2] Personal medical expenditures include spending on hospital services; physician, dentist and other professional services; prescription drugs and medical equipment; nursing home services, etc. These exclude expenses on the following items: net costs of health insurance, medical facilities construction, program administration, government public health activities and research. For 1930-1960, the data source is Worthington (1975). For 1960-2001, the data are obtained from the U.S. Centers for Medicare and Medicaid Services, "Health Accounts", <http://cms.hhs.gov/statistics/nhe/default.asp>. These data are then divided by the total civilian population and deflated by the GDP deflator.

[3] In the quantitative analysis, only those aged 25 or above will be considered. Thus it is of interest to consider the average spending of this group. Since these statistics are not readily obtainable, they are computed using the data reported in the technical appendix of Meara, White and Cutler (2004). Details of the computation can be found in Appendix A1. For 1950 and 2001, the average medical spending of those aged 25 years or above were $584 (in constant 2001 dollars) and $5,140, respectively. This implies an average annual growth rate of 4.36%.

[4] Another reason is that formal medicine played a significant role in reducing mortality during the same time period but not earlier on. Readers are referred to the historical discussions for further details.

[5] Data on personal consumption expenditures (PCE) are obtained from the Bureau of Economic Analysis, National Income and Product Accounts. The medical care component of PCE is replaced by the personal medical expenditures described in foonote 2. This is because the former includes net costs of health insurance.

rate for the non-elderly was 3.8%.[6]

The tremendous increase in medical expenditures was accompanied by (i) a decline in mortality and (ii) an expansion in insurance coverage. The declining trend in age-adjusted mortality and the corresponding increase in life expectancy are shown in Figure 4.[7] In the middle of the twentieth century, mortality rate stood at 1,446 per 100,000 population. Over the next 50 years, mortality dropped by 40% and became 855 per 100,000 population. An average American at age 25 in 1950 could expect to live 46.6 more years. This increased to 53.4 years by 2001.[8] An alternative way to describe the increase in longevity is to consider the proportion of population that survives to a certain age. Figure 5 compares the probability of being alive in various ages (conditional on being alive at age 25) between 1949-51 and 2001.[9] A significant outward expansion in survival probabilities was recorded over the passage of time.

Insurance coverage also expanded markedly during the post-war era. Between 1950 and 2001 the proportion of total civilian population covered by health insurance increased from 58% to 85.7%.[10] At the same time, private insurance became an increasingly important source of payment for personal health care [see Figure 6].[11] In 1950 68.3% of total personal health care expenses were paid directly by the consumers, whereas only 8.5% were paid by private insurance. Half a century later, out-of-pocket expenditures accounted for only 17% of the total spending, while 35% were paid by private insurance. Since the introduction of Medicare and Medicaid, the U.S. government has assumed a considerably larger role in financing the provision of health care. In 2001 43.4% of total medical spending were paid by the government.

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[6] See Appendix A1 for details.

[7] Mortality rates are *age-adjusted* when the underlying age composition is held constant as in certain base year. This makes comparisons across years meaningful. For the data reported here, the base year is 2000. Unless otherwise specified, all mortality rates reported in this work are age-adjusted and come from the same source: Centers for Disease Control and Prevention, National Center for Health Statistics, <http://www.cdc.org/nchs/about/major/dvs/mortdata.htm>.

Data on life expectancy can be found in *National Vital Statistics Reports*, v.52, no.14.

[8] Data on life expectancy are constructed using cross-sectional data on age-specific death rates for the designated years. These data include deaths due to events that are not directly related to health, such as accident, homicide and suicide. Although these three causes accounted for only 8.3% of all deaths in 1950 and 6.3% in 2001, they accounted for a large fraction of deaths among teenagers and young adults. Readers are referred to Tables A3 and A4 for detailed statistics. For the purpose of this paper, it is desirable to consider deaths caused by health-related events only. When deaths due to accident, homicide and suicide are removed, life expectancy at age 25 was 47.7 years in 1950 and 54.2 years in 2001.

[9] Deaths due to accident, homicide and suicide are removed when preparing these figures.

[10] Source: (i) 1950, Anderson and Feldman (1956), Table A1. (ii) 2001, U.S. Census Bureau, *Health Insurance Coverage, 2001.*

[11] Data source for Figure 6: (i) 1950-60, Worthington (1975), Table 6. (ii) 1970-2001, Centers for Medicare & Medicaid Services, <http://www.cms.hhs.gov/researchers/pubs/datacompendium/current.>

2.2 Historical Discussion

2.2.1 Before 1950

One of the most remarkable developments in the twentieth century is the rapid decline in mortality. In 1900 mortality rate stood at 2,518 per 100,000 population, while life expectancy at birth was just 47.3 years. This was a time when infectious diseases were rampant. Pneumonia, influenza and tuberculosis topped the list of leading killers at that time. These, together with diphtheria, measles, scarlet fever and whooping cough, accounted for 27% of all deaths. The influenza epidemic of 1918, which pushed the death rate to 2,542 per 100,000 population, demonstrated how devastating these diseases could be if left unchecked. The prevalence of infectious diseases also made young children's lives more vulnerable. Infant mortality rate was lamentably high at the beginning of the last century. One out of every six babies born could not survive their first year [see Table 1]. Children under 5 years of age accounted for 30% of all deaths while persons aged 65 and above accounted for only 24%. Over the ensuing fifty years, mortality rate fell by 42.6% while average lifespan extended by 20.9 years. The decline in mortality during early childhood was particularly impressive. By 1950 less than 10% of all deaths were for people under five years of age. The changing age composition of deaths is illustrated in Figure 7.

What caused these changes in mortality ? In particular, what was the role played by modern medical science ? Effective control over infectious diseases was the driving force behind the reduction in mortality during the first half of the twentieth century. This was primarily the result of rising living standards and improved public health measures, such as proper sewage disposal and purified water.[12] Formal medicine only played an ancillary role in the battle against infectious diseases at that time.

By the end of the nineteenth century, medical researchers had already identified the causes of various infectious diseases. But little was known on how to treat them. When effective medicine, such as penicillin and other antibiotics, finally emerged in the 1940s, infectious disease mortality was already under control [see Table 2]. The quality of medical practice during the earlier decades is also an issue of concern. Regulations on medical practice and medical education were nonexistent before 1920. This provided a breeding-ground for a large number of incompetent practitioners produced by proprietary medical schools. These schools would admit anyone who could afford the tuition fees

[12] Interested readers are referred to Dowling (1977) for a detailed and non-technical account on the battle against infectious diseases.

without regard to their academic background. Many specialists in the profession were self-named and poorly trained.[13] Even for well-trained physicians, there was not much they could do in terms of diagnosis and treatment. A physician recalled the state of the art in internal medicine in 1930 as follows:

> "We had only a few drugs to prescribe then, and our diagnostic aids were simple and crude. By contrast, a half century later, some thousands of drugs are available for use in the practice of internal medicine, most of which have been proved effective. ... Similarly with diagnostic procedures, there was little to be done up to 1930... . We had no chemical tests for blood levels of enzymes, electrolytes, gases, or hormones, and none of our modern imaging techniques were available." Beeson (1980).

Major reforms in medical education and practice had been undertaken since. Academic prerequisites for medical education were specified. Clinical teaching became part of the medical curriculum and internship was required for graduation. A system of board certification was established to regulate the professional accreditation of specialists. All these have had far-reaching impact on the quality of physicians and the public's perception towards them.

The first half of the twentieth century also witnessed a rapid development in private health insurance. The first generation of health insurance contracts, which were developed during the 1930s, took the form of prepayment plans organized by hospital associations, medical professions and community-consumer groups. Suffering from the accumulation of unpaid medical bills during the Great Depression, hospitals and physicians throughout the country adopted prepayment plans with the primary concern of ensuring payment. Most of the earlier plans offered full coverage without deductible for medical services up to a certain limit.[14] Because these contracts were intended to keep benefits low in amount and short in duration, subscribers were exposed to unexpected major medical expenses. Despite this undesirable feature, the spread of health insurance was swift. Within the decade of 1941-1950, the percentage of population enrolled for hospital benefits increased from 12.4% to 50.7%.[15]

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[13] Rosen (1983), p.82.

[14] Encouraged by the success of the prepayment associations, insurance companies also offered similar benefit patterns. The major difference is that insurance companies offered benefits in cash, whereas the prepayment associations offered benefits in services. Readers are referred to Faulkner (1960) for further details on the early health insurance plans.

[15] Source: Reed (1965).

2.2.2 After 1950

During the latter half of the twentieth century, infectious diseases were no longer a major threat towards public health. As more people survived to old age, the prevalence of chronic diseases became more alarming. In 1900 diseases of the heart and cancers together accounted for only 15.1% of all deaths.[16] Over the period 1900-1950, mortality rates of the two increased by 2.2 and 1.7 times, respectively [see Figure 8]. By the year 1950, 54.1% of all deaths were due to these diseases and the share remained over 50% since. During the 1950s and early 1960s the rising trend of life-expectancy was hindered by high death rates resulting from these two groups of diseases. The upward trend was not resumed until heart disease mortality began to decline sharply in the late 1960s [see Figures 4 and 8]. Between 1965 and 2001, heart disease mortality fell by 54.3%. This coincided with the advent of many innovations used in cardiovascular treatment. Evidence suggests that these innovations had made a significant contribution to the decline in mortality. Medical researchers Goldman and Cook (1984) reported that about 40% of the decline in coronary heart disease mortality over the period 1968-1976 can be attributed to life-saving innovations. More recently, Hunink, Goldman and Torsteson (1997) found that nearly half of the decline in coronary heart disease mortality during 1980-1990 was brought about by better medical treatment. Their results are supported by the work of Cutler, McClellan and Newhouse (1999), which found that 55% of the reduction in mortality from heart attacks during the period 1975-1995 can be attributed to improvement in medical treatment, especially the use of new pharmaceuticals.

As for cancers, despite the rising trend in cancer mortality, the probability of surviving the disease has been increasing during the post-war decades. The five-year relative survival rate for all forms of cancer increased from 35% to 62.7% over the period 1950-1995.[17] Again, the march of science has made a significant contribution. Lichtenberg (2004) found that new drugs that emerged after 1970 could account for 50-60% of the increase in age-adjusted survival rates in the first six years after diagnosis. All this evidence suggests that technological progress in medical treatment played an important role in saving lives during the second half of the twentieth century.

Meanwhile, the increasing prevalence of chronic diseases and the rapid growth in medical costs raised concerns on the financial costs of prolonged and catastrophic illnesses. Since 1948 insurance

[16] "Diseases of the heart" include ischemic (or coronary) heart diseases and other form of heart diseases.

[17] Lichtenberg (2004) argued that the increase in cancer mortality was largely the result of rising incidence.

companies began to offer a new type of plan, known as major medical expense policy, which provided coverage on the especially high costs of major and prolonged illnesses. The plan could be used either as a supplement for basic coverage, or as a separate comprehensive program. Conceivably, these policies would expose the insurers to tremendous liabilities. To ease these burdens, an initial deductible and a coinsurance provision were added so that the subscribers would bear some part of the costs. Over the period 1960-1986, the percentage of population protected by major medical expense policies increased from 17.6% to 65.8%.[18]

Another major development in the health insurance industry was the introduction of Medicare and Medicaid programs in 1966. The current study focuses on Medicare which targets primarily the elderly (over 65 years of age) population. One problem of the Medicare program is that it fails to cover very long hospital stays, which are highly expensive.[19] This exposes the beneficiaries to substantial medical expenditure risk. In response, over 60% of Medicare beneficiaries purchased supplementary private insurance in 2001.

3 The Economic Environment

The model economy is composed of overlapping generations. In each period, a continuum of *ex ante* identical agents is born. The size of cohort is growing at a constant rate $\gamma > 0$. Each agent begins his life with identical preferences, same level of health $(\overline{h})$ and zero wealth. In each period, each agent faces a positive probability of dying. The maximum age that one can live to is age J. Starting from age 0, an agent works until the exogenously given retirement age $I\,(< J)$ is reached. During the working years, an age-j agent is endowed with e_j units of effective labor which he supplies inelastically to the market. An individual supplies no labor when retired; i.e., $e_j = 0$ for $j = I+1, ..., J$. There is also a set of initial old agents. An agent who is of age $j \geq 1$ at time 0 is said to be of generation $-j$. The health stock of these initial old agents at time 0 is again given by $\overline{h}$.

In this economy there are two commodities: a consumption good and medical care. The former is produced by a neoclassical production function which will be described later. Each unit of consumption good can be transformed into $\frac{1}{p}$ units of medical care. All medical care is used to produce new units of health via the production function $i : \mathbb{R}_+ \rightarrow \mathbb{R}_+$. The function is assumed to be twice continuously

[18] Source: U.S. Bureau of Census, *Statistical Abstract of the U.S.*, various issues.

[19] A brief description on the risk-sharing structure of Medicare can be found in Appendix A2.

differentiable, strictly increasing and strictly concave. The accumulation process of health is given by

$$h' = i(m) + (1 - \delta_h) h + \varepsilon, \tag{1}$$

where h denotes health status at the beginning of the current age, h' is health status at the end of the current age, $\delta_h \in (0,1)$ is the depreciation rate of health and ε is a health shock. In each period, an agent faces an idiosyncratic health shock, ε, drawn from a finite set $\mathcal{E} = \{\varepsilon_1, ..., \varepsilon_S\}$. The severeness of the health shock is ranked according to $\varepsilon_1 = 0 > \varepsilon_2 > ... > \varepsilon_S$. This shock is assumed to be independently distributed over time and across agents. In addition, the probability distribution of the shock is assumed to be age-dependent.[20] Specifically, the probability of drawing $\varepsilon \in \mathcal{E}$ at age j is denoted by $\pi_j(\varepsilon)$, with $\sum_{\varepsilon \in \mathcal{E}} \pi_j(\varepsilon) = 1$ for all j.

Conditional on being alive at the current age with end-of-period health status h', the probability of surviving to the next period is $\Phi(h')$. The function $\Phi : \mathbb{R} \to [0,1]$ is made up of two parts: (i) for $h' > 0$, $\Phi(h')$ is twice continuously differentiable, strictly increasing, and satisfies $\lim_{h' \to \infty} \Phi(h') = 1$, (ii) for $h' \leq 0$, $\Phi(h') = 0$. The latter means death is certain when health falls below zero. Moreover, it is assumed that the composite function $\widehat{\Phi}(m) \equiv \Phi[i(m) + (1 - \delta_h) h + \varepsilon]$ is strictly concave.

Utility is zero when deceased. The period utility function for a living agent is given by $U(c)$, where c denotes current consumption. The utility function $U : \mathbb{R}_+ \to \mathbb{R}_{++}$ satisfies all the usual assumptions and strict positivity; i.e., $U(c) > 0$ for $c > 0$. The last assumption is added to ensure that being alive with positive consumption is always preferable to being dead.

The consumption good is produced according to a Cobb-Douglas production function,

$$\boldsymbol{y} = A \boldsymbol{k}^{\alpha} \boldsymbol{l}^{1-\alpha}, \quad \alpha \in (0,1), \tag{2}$$

where $\boldsymbol{y}$ denotes aggregate output, $\boldsymbol{k}$ denotes aggregate physical capital, A represents total factor productivity, and $\boldsymbol{l}$ is the aggregate labor input. The stock of physical capital accumulates according to

$$\boldsymbol{k}' = \boldsymbol{a} + (1 - \delta_k) \boldsymbol{k}, \tag{3}$$

with the initial level of capital, k_0, given. The variable $\boldsymbol{a}$ represents gross investment, and $\delta_k \in (0,1)$

[20] This assumption is motivated by the fact that chronic diseases are much more likely to occur among the elderly. In the quantitative analysis, only chronic diseases are considered.

is the depreciation rate of physical capital.

3.1 The Benchmark Economy in 1950

3.1.1 Market Structure

In the framework described above, agents face two types of uncertainty: uncertainty concerning their end-of-period health and uncertainty with respect to the length of their lifetime. This section describes an economy in which agents can insure against the health risk but not the mortality risk. In this economy, there is a private insurance market in which reimbursement health insurance contract is being traded. Private annuities are missing, so agents cannot protect themselves against the uncertainty in consumption brought by an uncertain length of lifetime. In terms of investment opportunities, physical capital is the only channel for investment and agents are not allowed to borrow. In the quantitative analysis, this model is used to represent the U.S. economy in 1950, a time before the Medicare program is implemented. Hence, public health insurance is not considered in here.

In the private insurance market, insurance companies cannot observe the health status of their customers. All these companies can observe are their customers' medical expenses. As a result, insurance benefits are paid as reimbursement on the actual expenses, which are controlled by the insured. It is assumed that a standard, perfectly divisible contract is being traded. This means agents can buy any positive amount, $\widetilde{x} \geq 0$, of this contract. The health insurance contract is characterized by a premium rate π_p and a piecewise linear reimbursement function $\Theta : \mathbb{R}_+ \rightarrow \mathbb{R}_+$. The latter is a function of the actual expenses incurred by the insured, pm, and takes the following form

$$\Theta\left(pm\right) = \begin{cases} 0 & \text{if } pm \leq d \\ \kappa\left(pm - d\right) & \text{if } pm \in [d, l] \\ L & \text{if } pm > l, \end{cases}$$

where $d \geq 0$ is the deductible, $\kappa \in (0, 1)$ is the coinsurance rate and L is the maximum amount that the insurance company is willing to pay.[21] The reimbursement function is assumed to be continuous

[21] Suppose an agent with a medical bill pm purchased $\widetilde{x} > 0$ units of insurance. The agent would split the medical bill into $\widetilde{x}$ shares and subject each portion to a separate reimbursement schedule. His out-of-pocket expenditures are then given by

$$pm - \widetilde{x}\Theta\left(pm/\widetilde{x}\right) = \begin{cases} pm & \text{if } pm/\widetilde{x} \leq d \\ \left(1-\kappa\right)pm + \widetilde{x}\kappa d & \text{if } pm/\widetilde{x} \in [d, l] \\ pm - \widetilde{x}L & \text{if } pm/\widetilde{x} \geq l. \end{cases}$$

on $\mathbb{R}_+$, so $L = \kappa (l - d)$.

In the absence of an annuity market, agents who die prematurely (before age J) will leave behind their wealth as accidental bequests. These are distributed to all of the survivors in a lump-sum fashion.

The sequence of events is as follows: At the beginning of each period, an agent chooses the amount of private health insurance and a set of state-contingent decision rules for consumption, medical care and savings. All these decisions are made before the current health shock is realized. After it is realized, commodities specified by the decision rules are delivered and reimbursement from the insurance is made. Before the end of the period, the agent is informed whether or not he will survive in the next period.

3.1.2 Individual's Problem

Consider an age-j agent who enters the period with characteristics $\boldsymbol{\theta} = (h, s_{-1})$, where s_{-1} is previous savings in terms of physical capital. Let w be the market wage rate for effective unit of labor, r be the (gross) return from physical capital and b be the per-capita amount of accidental bequests. The agent chooses the amount of insurance and a set of state-contingent decision rules, denoted by $\boldsymbol{\varphi} = \{\widetilde{x}_j(\boldsymbol{\theta}), c_j(\boldsymbol{\theta}, \varepsilon), m_j(\boldsymbol{\theta}, \varepsilon), s_j(\boldsymbol{\theta}, \varepsilon) | \varepsilon \in \mathcal{E}\}$, to solve the following problem

$$E^j \left[V^j(\boldsymbol{\theta}, \varepsilon)\right] = \max_{\boldsymbol{\varphi}} E^j \left\{U\left[c_j(\boldsymbol{\theta}, \varepsilon)\right] + \beta \Phi \left[h_{j+1}(\boldsymbol{\theta}, \varepsilon)\right] E^{j+1} \left[V^{j+1}\left(\boldsymbol{\theta}', \varepsilon'\right)\right]\right\} \tag{P1}$$

subject to

$$c_j(\boldsymbol{\theta}, \varepsilon) + p m_j(\boldsymbol{\theta}, \varepsilon) + s_j(\boldsymbol{\theta}, \varepsilon) = w e_j + r s_{-1} + b + \widetilde{x}_j(\boldsymbol{\theta}) \left\{\Theta\left[\frac{p m_j(\boldsymbol{\theta}, \varepsilon)}{\widetilde{x}_j(\boldsymbol{\theta})}\right] - \pi_p\right\},$$

$$h_{j+1}(\boldsymbol{\theta}, \varepsilon) = i\left[m_j(\boldsymbol{\theta}, \varepsilon)\right] + (1 - \delta_h) h + \varepsilon,$$

$$s_j(\boldsymbol{\theta}, \varepsilon) \geq 0,$$

for $\varepsilon \in \mathcal{E}$ and $\widetilde{x}_j(\boldsymbol{\theta}) \geq 0$.

Denote by $\boldsymbol{z}^j = \left(\varepsilon^0, ..., \varepsilon^j\right)$ a history of health shock up to age j and let $\mathcal{Z}^j$ be the set of all possible $\boldsymbol{z}^j$. The notation $\boldsymbol{z}^{-1}$ is used to denote the empty past history of a newborn agent. The following lemma establishes that the agent's decisions for consumption, medical spending, saving and insurance can be expressed solely as a function of the history of health shocks.

Lemma 1 *The solution of (P1) can be expressed as* $c_j(\boldsymbol{z}^j)$, $m_j(\boldsymbol{z}^j)$, $s_j(\boldsymbol{z}^j)$ *and* $\widetilde{x}_j(\boldsymbol{z}^{j-1})$.

Proof. See Appendix B. ■

3.1.3 Competitive Equilibrium

This section describes a competitive equilibrium for a stationary environment in which the life-cycle patterns of individual consumption, medical spending and savings are time-invariant. It follows that all the aggregate variables and the population structure are time-invariant in this environment.

Let $N(\boldsymbol{z}^j)$ denote the measure of all age-j agents with shock history $\boldsymbol{z}^j$. The population measure evolves according to

$$N\left(\boldsymbol{z}^j\right) = \pi_j(\varepsilon)\,\widetilde{\Phi}\left[h_j\left(\boldsymbol{z}^{j-1}\right)\right] N\left(\boldsymbol{z}^{j-1}\right), \qquad \text{for } j = 1, ..., J, \tag{4}$$

with $\boldsymbol{z}^j = \left(\boldsymbol{z}^{j-1}, \varepsilon\right)$, $\widetilde{\Phi}\left[h_j\left(\boldsymbol{z}^{j-1}\right)\right] \equiv \Phi\left[h_j\left(\boldsymbol{z}^{j-1}\right)\right]/(1+\gamma)$, and

$$N\left(\boldsymbol{z}^0\right) = \pi_0(\varepsilon), \tag{5}$$

for $\boldsymbol{z}^0 = \varepsilon \in \mathcal{E}$. The size of the total population is given by

$$\overline{N} = \sum_{j=0}^{J} \sum_{\boldsymbol{z}^j} N\left(\boldsymbol{z}^j\right).$$

Among those age-j agents with shock history $\boldsymbol{z}^j$, a fraction $\left\{1 - \Phi\left[h_{j+1}\left(\boldsymbol{z}^j\right)\right]\right\}$ will be deceased in the next period. Each deceased agent will leave behind an amount $rs_j(\boldsymbol{z}^j)$. The amount of bequest received by each survivor is thus given by

$$b = \frac{1}{\overline{N}} \sum_{j=0}^{J-1} \sum_{\boldsymbol{z}^j} N\left(\boldsymbol{z}^j\right) \left\{1 - \Phi\left[h_{j+1}\left(\boldsymbol{z}^j\right)\right]\right\} rs_j\left(\boldsymbol{z}^j\right) = 0. \tag{6}$$

All the savings are channelled to the capital market. The capital market clears when aggregate demand equals aggregate supply; i.e.,

$$\boldsymbol{k} = \sum_{j=0}^{J} \sum_{\boldsymbol{z}^j} N\left(\boldsymbol{z}^j\right) s_j\left(\boldsymbol{z}^j\right). \tag{7}$$

In the consumption good sector, firms hire labor and rent physical capital from the factor markets to produce output according to (2). Both goods and factor markets are assumed to be perfectly competitive, hence

$$r = \alpha A \boldsymbol{k}^{\alpha-1} \boldsymbol{l}^{1-\alpha} + 1 - \delta_k, \tag{8}$$

$$w = (1-\alpha) A \boldsymbol{k}^{\alpha} \boldsymbol{l}^{-\alpha}. \tag{9}$$

The consumption good market clears when

$$\sum_{j=0}^{J} \sum_{\boldsymbol{z}^j} N\left(\boldsymbol{z}^j\right) \left[c_j\left(\boldsymbol{z}^j\right) + p m_j\left(\boldsymbol{z}^j\right)\right] + \delta_k \boldsymbol{k} = A \boldsymbol{k}^{\alpha} \boldsymbol{l}^{1-\alpha}. \tag{10}$$

The labor market clears when the following holds,

$$\boldsymbol{l} = \sum_{j=0}^{I} \sum_{\boldsymbol{z}^j} N\left(\boldsymbol{z}^j\right) e_j. \tag{11}$$

The private insurance market is assumed to be perfectly competitive. The insurance premium, π_p, is endogenously determined by the market-clearing condition:

$$\sum_{j=0}^{J} \sum_{\boldsymbol{z}^{j-1}} \sum_{\boldsymbol{\varepsilon} \in \mathcal{E}} N\left(\boldsymbol{z}^{j-1}, \varepsilon\right) \widetilde{x}_j\left(\boldsymbol{z}^{j-1}\right) \left\{ \Theta\left[\frac{p m_j\left(\boldsymbol{z}^{j-1}, \varepsilon\right)}{\widetilde{x}_j\left(\boldsymbol{z}^{j-1}\right)}\right] - \pi_p \right\} = 0. \tag{12}$$

A competitive equilibrium for this economy is defined below:

Definition 2 *A competitive equilibrium for this economy consists of allocations for all types of agents* $\boldsymbol{\varphi} = \left\{c_j\left(\boldsymbol{z}^{j-1}, \varepsilon\right), m_j\left(\boldsymbol{z}^{j-1}, \varepsilon\right), s_j\left(\boldsymbol{z}^{j-1}, \varepsilon\right), \widetilde{x}_j\left(\boldsymbol{z}^{j-1}\right) | \boldsymbol{z}^{j-1} \in \mathcal{Z}^{j-1}, \varepsilon \in \mathcal{E}\right\}_{j=0}^{J}$*, a set of prices* $\{r, w, \pi_p\}$*, factor inputs* $\{\boldsymbol{k}, \boldsymbol{l}\}$*, population measures* $\left\{N\left(\boldsymbol{z}^j\right) | \boldsymbol{z}^j \in \mathcal{Z}^j\right\}_{j=0}^{J}$*, and per-capita bequest* b *such that*

1. *Given the prices and bequest,* $\boldsymbol{\varphi}$ *solves the agent's problem.*

2. *Factor inputs and prices,* $\{\boldsymbol{k}, \boldsymbol{l}, r, w\}$*, satisfy (8) and (9).*

3. *The population measures evolve according to (4) and (5).*

4. *Per-capita bequest,* b*, is given by (6).*

5. *All markets clear; i.e., (7), (10), (11) and (12) hold.*

3.2 The Benchmark Economy in 2001

3.2.1 Market Structure

Moving forward across time, the year is now 2001. The only difference between 1950 and 2001 in terms of insurance opportunity is that public health insurance programs, such as Medicare and Medicaid, are present in 2001. To capture this, a public health insurance program similar to Medicare is introduced into the economy described above. In the quantitative exercise, this version of the benchmark economy is calibrated to mimic the U.S. economy in 2001.

Under the public health insurance program, all retirees are automatically enrolled at zero cost. The program offers a reimbursement schedule $\Theta_g : \mathbb{R}_+ \rightarrow \mathbb{R}_+$ that is similar to private insurance,

$$\Theta_g(pm) \begin{cases} 0 & \text{if } pm \leq d_g \\ \kappa_g(pm - d_g) & \text{if } pm \in [d_g, l_g] \\ L_g & \text{if } pm > l_g. \end{cases}$$

Notice that for $pm > 0$, the program covers only part of the medical expenses. This creates an incentive for the retirees to purchase supplementary insurance from the private health insurance market to cover the differences, $pm - \Theta_g(pm)$, that are not insured by the public health insurance program. The public insurance program is financed by a payroll tax $\tau \in (0,1)$ imposed on the working population. For the working agents, private health insurance is the only source of insurance. Expenditures on private insurance can be deducted from the payroll tax. The rest of the economy is the same as that described in section 3.1.1.

3.2.2 Individual's Problem

First, consider a retired agent of age $j > I$ who begins the period with characteristics $\boldsymbol{\theta} = (h, s_{-1})$. His task is to choose $\boldsymbol{\varphi} = \{\widetilde{x}_j(\boldsymbol{\theta}), c_j(\boldsymbol{\theta},\varepsilon), m_j(\boldsymbol{\theta},\varepsilon), s_j(\boldsymbol{\theta},\varepsilon) | \varepsilon \in \mathcal{E}\}$ in order to maximize the expected value of his remaining life,

$$E^j\left[V^j(\boldsymbol{\theta},\varepsilon)\right] = \max_{\boldsymbol{\varphi}} E^j\left\{U\left[c_j(\boldsymbol{\theta},\varepsilon)\right] + \beta\Phi\left[h_{j+1}(\boldsymbol{\theta},\varepsilon)\right]E^{j+1}\left[V^{j+1}\left(\boldsymbol{\theta}',\varepsilon'\right)\right]\right\} \tag{P2}$$

subject to

$$c_j(\boldsymbol{\theta},\varepsilon) + v_j(\boldsymbol{\theta},\varepsilon) + s_j(\boldsymbol{\theta},\varepsilon) = rs_{-1} + b + \widetilde{x}_j(\boldsymbol{\theta})\left\{\Theta\left[\frac{v_j(\boldsymbol{\theta},\varepsilon)}{\widetilde{x}_j(\boldsymbol{\theta})}\right] - \pi_p\right\},$$

$$v_j(\boldsymbol{\theta},\varepsilon) = pm_j(\boldsymbol{\theta},\varepsilon) - \Theta_g[pm_j(\boldsymbol{\theta},\varepsilon)],$$

$$h_{j+1}(\boldsymbol{\theta},\varepsilon) = i[m_j(\boldsymbol{\theta},\varepsilon)] + (1-\delta_h)h + \varepsilon,$$

$$s_j(\boldsymbol{\theta},\varepsilon) \geq 0,$$

for $\varepsilon \in \mathcal{E}$ and $\widetilde{x}_j(\boldsymbol{\theta}) \geq 0$. The variable $v_j(\boldsymbol{\theta},\varepsilon)$ represents the amount of medical expenditures that are not covered by public insurance but potentially covered by supplementary private insurance.

Next, consider an agent of working age ($j \leq I$) with characteristics $\boldsymbol{\theta} = (h, s_{-1})$. His problem can be expressed as

$$E^j\left[V^j(\boldsymbol{\theta},\varepsilon)\right] = \max_{\boldsymbol{\varphi}} E^j\left\{U(c) + \beta\Phi[h_{j+1}(\boldsymbol{\theta},\varepsilon)]E^{j+1}\left[V^{j+1}(\boldsymbol{\theta}',\varepsilon')\right]\right\} \tag{P2$'$}$$

subject to

$$c_j(\boldsymbol{\theta},\varepsilon) + pm_j(\boldsymbol{\theta},\varepsilon) + s_j(\boldsymbol{\theta},\varepsilon) = (1-\tau)[we_j - \pi_p\widetilde{x}_j(\boldsymbol{\theta})] + rs_{-1} + b + \widetilde{x}_j(\boldsymbol{\theta})\Theta\left[\frac{pm_j(\boldsymbol{\theta},\varepsilon)}{\widetilde{x}_j(\boldsymbol{\theta})}\right],$$

$$h_{j+1}(\boldsymbol{\theta},\varepsilon) = i[m_j(\boldsymbol{\theta},\varepsilon)] + (1-\delta_h)h + \varepsilon,$$

$$s_j(\boldsymbol{\theta},\varepsilon) \geq 0,$$

for $\varepsilon \in \mathcal{E}$ and $\widetilde{x}_j(\boldsymbol{\theta}) \geq 0$. As in section 3.1.2, all the decision rules can be expressed in terms of the shock history.

3.2.3 Competitive Equilibrium

In this economy, the only function of the government is to maintain the public insurance program and balance its budget in every period. The government's budget constraint is given by

$$\tau\sum_{j=0}^{J}\sum_{\boldsymbol{z}^{j-1}}\sum_{\boldsymbol{\varepsilon}\in\mathcal{E}} N\left(\boldsymbol{z}^{j-1},\varepsilon\right)\left[we_j - \pi_p\widetilde{x}_j\left(\boldsymbol{z}^{j-1}\right)\right] = \sum_{j=I+1}^{J}\sum_{\boldsymbol{z}^j} N\left(\boldsymbol{z}^j\right)\Theta_g\left[pm_j\left(\boldsymbol{z}^j\right)\right]. \tag{13}$$

On the left-hand side is the total payroll tax collected less the tax-deductible expenditures on private health insurance. The right-hand side gives the total reimbursement received by the beneficiaries of the public insurance program.[22] The rest of the economy is the same as that described in section 3.1.3.

A competitive equilibrium for this economy is defined as follow:

Definition 3 *A competitive equilibrium for this economy consists of allocations for all types of agents,* $\boldsymbol{\varphi} = \left\{c_j\left(\boldsymbol{z}^{j-1}, \varepsilon\right), m_j\left(\boldsymbol{z}^{j-1}, \varepsilon\right), s_j\left(\boldsymbol{z}^{j-1}, \varepsilon\right), \widetilde{x}_j\left(\boldsymbol{z}^{j-1}\right) | \boldsymbol{z}^{j-1} \in \mathcal{Z}^{j-1}, \varepsilon \in \mathcal{E}\right\}_{j=0}^{J}$, *a set of prices* $\{r, w, \pi_p\}$, *factor inputs* $\{\boldsymbol{k}, \boldsymbol{l}\}$, *population measures* $\left\{N\left(\boldsymbol{z}^j\right) | \boldsymbol{z}^j \in \mathcal{Z}^j\right\}_{j=0}^{J}$, *income tax rate* τ *and per-capita bequest* b *such that*

1. *Given the prices and bequest,* $\boldsymbol{\varphi}$ *solves agents' problem.*
2. *Factor inputs and prices,* $\{\boldsymbol{k}, \boldsymbol{l}, r, w\}$, *satisfy (8) and (9).*
3. *The population measures evolve according to (4) and (5).*
4. *Per-capita bequest,* b, *is given by (6).*
5. *The government's budget is balanced in each period, i.e. (13) holds.*
6. *All markets clear; i.e., (7), (10), (11) and (12) hold.*

3.3 The Economy with No Insurance

This section describes an economy in which agents are cut off from all insurance markets. To insure themselves against consumption fluctuations brought by the health shock and mortality risk, the agents can only adjust their holdings of physical capital. Again, agents are not allowed to borrow. The agent's problem is to choose a set of state-contingent decision rules, $\boldsymbol{\varphi} = \{c_j(\boldsymbol{\theta}, \varepsilon), m_j(\boldsymbol{\theta}, \varepsilon), s_j(\boldsymbol{\theta}, \varepsilon) | \varepsilon \in \mathcal{E}\}$, in order to maximize the expected value for the remaining lifetime. Formally, this is written as

$$E^j\left[V^j(\boldsymbol{\theta}, \varepsilon)\right] = \max_{\boldsymbol{\varphi}} E^j\left\{U\left[c_j(\boldsymbol{\theta}, \varepsilon)\right] + \beta\Phi\left[h_{j+1}(\boldsymbol{\theta}, \varepsilon)\right] E^{j+1}\left[V^{j+1}\left(\boldsymbol{\theta}', \varepsilon'\right)\right]\right\} \tag{P3}$$

subject to

$$c_j(\boldsymbol{\theta}, \varepsilon) + p m_j(\boldsymbol{\theta}, \varepsilon) + s_j(\boldsymbol{\theta}, \varepsilon) = w e_j + r s_{-1} + b,$$

$$h_{j+1}(\boldsymbol{\theta}, \varepsilon) = i\left[m_j(\boldsymbol{\theta}, \varepsilon)\right] + (1 - \delta_h) h + \varepsilon,$$

[22] In the quantitative analysis, the tax rate τ is taken as exogenously given, while reimbursement function $\Theta_g(\cdot)$ is endogenously determined.

for $\varepsilon \in \mathcal{E}$. Since this is just a special case of the benchmark model, a competitive equilibrium for this economy can be defined in a similar fashion.

4 Quantitative Analysis

The objective of the calibration exercise is to construct two steady states, based on the benchmark economies, to represent the U.S. economy in 1950 and 2001. Most of the parameters in the model can be readily obtained from the data. For those that cannot, a minimization procedure is used to determine their values. Table 3 summarizes all the parameters used in the baseline calibration.

Demography In the model economy, one period takes 5 years. Individuals are assumed to be economically active at age 25. Thus "age 0" in the model refers to the 25-29 age group. Take $I = 7$ and $J = 15$ so that retirement begins at age 65 and the oldest age group is 100-104. Over the period 1950-2001, the U.S. population grew at an average rate of 1.25% per year. In the model, the parameter γ corresponds to the 5-year population growth rate. Hence, $\gamma = (1.0125)^5 - 1 = 0.064$.

The survival probability function, $\Phi(\cdot)$, is assumed to take the form of the cumulative distribution function of a Weibull distribution:

$$\Phi(h) = 1 - \exp\left(-\psi h^{\theta}\right), \quad \text{for } h \geq 0,$$

with $\psi > 0$ and $\theta > 0$. Both ψ and θ are determined by the minimization procedure. The initial level of health at age 0, $\overline{h}$, is assumed to be constant over time and is normalized to 100.

Preferences and Earnings The period utility function takes the standard CRRA form; i.e., $U(c) = \frac{c^{1-\sigma}}{1-\sigma}$. Conventionally, the coefficient of relative risk aversion is no less than one. But then utility might be negative for some positive values of consumption. Thus, the coefficient must be strictly less than one in order to ensure strict positivity of utility. In the baseline calibration, the coefficient of relative risk aversion is set to 0.97. Section 5.3 reports how the main findings are affected when this coefficient varies. The annual subjective discount factor is taken to be 0.98, so $\beta = (0.98)^5 = 0.904$. The age-specific effective units of labor, $\{e_j\}_{j=0}^{7}$, are calibrated using data on money earnings in 1950 and

2001.[23] The parameter values are reported in Table 3b.

Production Technology In the production function for the consumption good, labor's share of income is fixed at 0.67, so $\alpha = 0.33$. The annual depreciation rate for physical capital is taken to be 10%. Hence, $\delta_k = 1 - (1 - 0.1)^5 = 0.410$.

Morbidity At each age, there are two possible values of health shock, $\{\varepsilon_1, \varepsilon_2\}$. The first one corresponds to the state of being "healthy", or one without any negative health shock so that $\varepsilon_1 = 0$. The second one corresponds to the state of being "sick". In the current context, being "sick" means suffering from either coronary heart disease (CHD) or cancers of any form.[24] The probabilities of the two states are computed using the incidence rates of these diseases. Figures 9 and 10 plot the average annual age-specific incidence rates for CHD and cancers, respectively.[25] Let q_j^h be the annual incidence rate for CHD at age j and q_j^c be the corresponding rate for cancers. In the model, being "healthy" means not suffering from CHD *and* not suffering from cancers for a period of five years. Hence, the probability of being "healthy" at age j is

$$\pi_j(\varepsilon_1) = \left[\left(1 - q_j^h\right)\left(1 - q_j^c\right)\right]^5.$$

The probability of being "sick" is $\pi_j(\varepsilon_2) = 1 - \pi_j(\varepsilon_1)$. The values of these probabilities are listed in Table 3c. The magnitude of the negative health shock (ε_2) is determined by the minimization procedure.

Medical Technology and Prices The production function for health at time t is specified as follows:

$$i_t(m) = \eta_t m^{\xi}, \tag{14}$$

where $\eta_t > 0$ and $\xi \in (0, 1)$. The productivity of medical care at time t is captured by η_t, while the cost of medical care is p_t. Both are exogenously given in the current model. Intuitively, medical care

[23] For 1950, data on wage and salary incomes obtained from the IPUMS general sample are used. For 2001, mean earnings by age reported in the Current Population Surveys are used. The labor endowment of those aged 25-29 in 1950 is normalized to unity. The effective units of labor for all other demographic groups are then derived by the ratio of mean earnings of that group to the mean earnings of the reference group.

[24] The importance of these diseases are discussed in section 2.2.2.

[25] Despite their alarming prevalence during the post-war era, nationwide data concerning the incidence of CHD and cancers are not available until the 1980s. Source: (i) CHD, The Atherosclerosis Risk in Communities Study (ARIC), <http://www.cscc.unc.edu/aric>. (ii) Cancers, National Cancer Institute, *SEER Cancer Statistics Review*, various issues.

includes such commodities as a hospital stay or a physician visit, which are inputs into the production for health. Innovations in medical treatment are likely to raise the price of these inputs because they are now more productive, and lower the price of output (i.e., health). Given the specific functional form in (14), the price of health in terms of consumption is given by

$$\frac{p_t}{i_t'(m)} = \frac{p_t}{\eta_t \xi} m^{1-\xi}.$$

Holding other things constant, the price of health would fall if η_t grows faster than p_t.

In the health economics literature, attempts to quantify the pace of technological progress in medical treatment are sparse. In a recent study, Lichtenberg and Virabhak (2002) estimated the rate of technological progress embodied in different vintages of drugs. The estimated growth rate ranged from 3.1% to 4.2% depending on the measure of health.[26] In the calibration, the average annual growth rate of η_t is taken to be 3.4%. Hence, $\eta_{2001} = (1.034)^{51} \eta_{1950}$. As for medical inflation, it is measured by the rate of change of the medical care component in the CPI relative to the general price level. Over the period 1950-2001, this component inflated at an average annual rate of 2.1% relative to the GDP deflator.[27] The cost of medical care in 2001 is determined by $p_{2001} = (1.021)^{51} p_{1950}$. In the baseline calibration, the price of medical care in 1950 is normalized to 10. In section 5.3, it is shown that the main findings are not sensitive to the choice of p_{1950}. The growth rates of η and p, together with the functional form in (14), imply that the price of health declined at an average annual rate of 1.26% over the period 1950-2001.[28]

Health Insurance In the calibration, all hypothetical insurance contracts are assumed to be major medical expense contracts. During the 1950s, a typical contract of this sort had an initial deductible ranging from \$50 to \$500 (in current dollars) and a coinsurance clause that required the insured to pay 20% to 25% of the expenses above the deductible.[29] In 2001, a typical contract in the private insurance

[26] There are two additional reasons why these results are suitable for the current study. First, Lichtenberg and Virabhak considered drugs that are approved over an extensive time period, from 1939 to 1998. Second, these estimates are based on a "dynamic" equation in which the pre-treatment (or beginning-of-period) health is controlled for. This "dynamic" equation is analogous to equation (1) in the current work.

[27] Admittedly the medical CPI may not be the best measure of medical inflation. A detailed account on the construction and shortcomings of this subindex can be found in Berndt et al (2001). This is used because there is no alternative measure for *general* medical inflation that covers the period in question.

[28] Cutler, McClellan, Newhouse and Remler (1998) estimated the quality-adjusted cost of treating heart attack over the period 1983-1994. Similar to the current study, they use length of life as the measure of health. According to their benchmark estimate, the quality-adjusted cost fell at an average annual rate of 1.1%.

[29] Source: Reed (1965).

market had the same range of coinsurance rate and a deductible that varied between \$250 and \$2500 (in current dollars). In the calibration, all private insurance contracts have the same coinsurance rate of 75%; i.e., $\kappa_{1950} = \kappa_{2001} = 0.75$. In the 1950 and 2001 steady states, the deductible are taken to be \$100 and \$250 (in current dollars), respectively.

As for Medicare in 2001, the cost-sharing structure is simplified so that it shares the same structure as private insurance. Specifically, it involves a deductible of \$892 and a coinsurance rate of 75%; i.e., $\kappa_g = 0.75$.

The Remaining Parameters Up to this point, the values of nine parameters are not yet determined. These include parameters in the survival probability function (ψ, θ) and the health production function (η_{1950}, ξ), the depreciation rate of health capital (δ_h), the magnitude of the negative health shock (ε_2), and the maximum reimbursement levels for health insurance $(L_{1950}, L_{2001}, L_g)$. A minimization procedure is used to determine these parameter values. The idea is to choose these values so that the model could match, as closely as possible, the nine real-world statistics listed in Table 4. Formally, let $\boldsymbol{\chi}$ be a (column) vector of parameters, and $\mathcal{S}$ be a (column) vector of selected real-world statistics. Given $\boldsymbol{\chi}$, the model could yield a prediction on $\mathcal{S}$, denoted by $\widehat{\mathcal{S}}(\boldsymbol{\chi})$. The minimization procedure then involves solving the following problem:

$$\min_{\boldsymbol{\chi}} \left[\widehat{\mathcal{S}}(\boldsymbol{\chi}) - \mathcal{S}\right]^T \left[\widehat{\mathcal{S}}(\boldsymbol{\chi}) - \mathcal{S}\right].$$

5 Findings

This section is organized into three parts. The first part documents the main findings obtained from the benchmark economies. These findings are summarized in Table 5. The second part reports the results obtained when the parameterization described in section 4 is imposed on the economy with no insurance. The same subsection also answers the question that motivates the current work, namely *"How much increase in life expectancy and medical spending can be attributed to technological progress in medical treatment and rising income ?"* The last part of this section illustrates how the baseline results are affected when some of the parameters vary.

5.1 Findings from Benchmark Economy

Medical Expenditures Under the baseline parameterization, the model is able to capture the expansion in medical spending between 1950 and 2001. In the model economy, the share of medical spending in GDP increases from 3.7% to 12.4%. In terms of personal consumption expenditures (PCE), the share of medical spending increases from 4.8% to 16.6%. Between the two steady states, real per-capita medical spending increase by a factor of 9.13. The actual growth factor between 1950 and 2000 is 8.81. In terms of annual growth rate, the predicted value is 4.43%, while the actual rate is 4.44%. As a reference, real per-capita GDP increases at an average annual rate of 2.0% in the model economy and the actual rate is 2.1%. In the 1950 steady state, 68.2% of the total medical spending is paid directly by the consumers. In the 2001 steady state, out-of-pocket expenditures accounted for 24.7% of the total spending, while Medicare accounted for 15.5%. This shows that there is a large expansion in third-party payments in the model economy.

Life Expectancy The model's predictions on life expectancy are depicted in Figures 11 and 12. The underlying survival probabilities are shown in Figures 13 and 14. Under the baseline parameterization, life expectancy increases by 4.1 years at age 25, 4.0 years at age 45 and 3.1 years at age 65. When compared to the data, the model is able to explain 64.6% of the increase in life expectancy at age 25, 67.8% at age 45 and 79.5% at age 65. Various measures are devised to capture the overall changes in life expectancy. The results are reported in Table 6.[30] In summary, the model can explain more than 60% of the increase in average life expectancy. The precise number depends on which measure is used.

Life-cycle Medical Spending This subsection examines the model's predictions on the life-cycle patterns of medical spending. Figures 15 and 16 show the predicted and observed ratio of medical spending to income across various age groups.[31] According to the data, this ratio is roughly constant

[30] The first measure of average life expectancy is constructed as below:

$$\overline{\Gamma}_{1t} = \sum_{j=0}^{J} \Psi_{j,t}\Gamma_{j,t}, \qquad \text{for } t = 1950, 2001,$$

where $\Psi_{j,t}$ is the population share of age-j agents at time t and $\Gamma_{j,t}$ denotes life expectancy at age j. The second measure is constructed by holding the population structure constant as in 1950. In practice, this involves replacing $\Psi_{j,t}$ with $\Psi_{j,1950}$ in the above expression. The third measure is constructed by holding the population structure constant as in 2001. The numbers reported in Table 6 are the differences between the two time periods.

[31] The actual numbers can be found in Table 7 panel A. These are the ratios of average medical spending for a particular age group to the average income of that group. For 1950, median incomes reported in *Census of Population: 1950*, vol.

during ages 25 to 64 and increases significantly afterwards. The current model is able to replicate these patterns. In the 1950 steady state, the ratio of medical spending to income before and after age 65 are 0.04 and 0.105, respectively. In the data, the corresponding figures are 0.037 and 0.117. In 2001, the predicted values are 0.123 and 0.635 while the observed values are 0.096 and 0.612. In the model, the mild increase before age 65 is largely the result of a low depreciation rate in health. The intuition is as follow. Since the probability of being sick when young is very low, the main reason why a young agent would invest in his health is to offset the depreciation. A low depreciation rate in health thus implies a low growth rate in medical spending when young. The model is able to yield reasonable predictions on the growth rate of medical spending by age. The predicted growth rate of medical spending among the elderly and the non-elderly are 5.48% and 4.26%, respectively. The actual growth rates over the period 1950-2000 are 5.41% and 3.81% [see Table 7 panel B].

One problem with the current model is that it predicts a sharp decline in spending among those over 75 years of age. The predicted life-cycle profiles of medical spending thus exhibit a hump-shaped pattern which is not observed in the data. This reflects a low demand for health among the oldest agents in the model. In general, these agents are poor in health and have a short expected lifespan. The former factor encourages investment in health while the latter suppresses it. The quantitative results suggest that the suppressing force dominates. In the current framework, health is demanded only because it extends life. Admittedly this ignores other attributes of health. Daily experience suggests that a person with poor health may not face any immediate risk of losing life but may suffer from some form of disability. Recent studies on medical spending have shown that disability status is closely related to spending among the elderly. Focusing on the Medicare beneficiaries in 1989-1990, Cutler and Meara (2001) reported that an average person aged 85 or above spent almost $2,000 more on medical care than one aged 65-69. Most importantly, a large part of these differences can be explained by differences in disability status. Ignoring other attributes of health may be the reason why the model tends to underestimate the average spending for the elderly.

Life-cycle Consumption It is well documented that life-cycle consumption profiles are hump-shaped in nature. In a recent study, Fernandez-Villaverde and Krueger (2007) estimated the life-cycle consumption profiles using data from the Consumer Expenditures Survey over the period 1980-

II, Table 139 are used. For 2000, data on median incomes are obtained from U.S. Census Bureau, Current Population Survey, <http://www.census.gov/hhes/www/income/income01/inctab7.html>.

1998. They found that after adjusting for life-cycle changes in family size, non-durable consumption peaked at age 52 and was about 29% higher than that at age 25. The current model is able to yield similar hump-shaped patterns but the peaks are lower than that reported by Fernandez-Villaverde and Krueger. In the 1950 steady state, consumption reaches its peak at ages 45-49.[32] The peak level is about 19% higher than that in ages 25-29. In the 2001 steady state, consumption peaks at ages 50-54. The ratio of peak consumption to that in ages 25-29 is around 1.18.

5.2 Findings from the Economy with No Insurance

Table 8 compares the results obtained from the two economies under the same parameterization. Two observations can be made from these findings. First, in both 1950 and 2001 the economy with no insurance could yield similar (but slightly lower) levels of life expectancy with fewer medical spending. When all insurance opportunities are removed, the share of medical spending in GDP would be lowered by 1.6 percentage points in 1950 and 1.4 percentage points in 2001. In terms of real per-capita spending, these represent a 43% reduction in 1950 and a 11% reduction in 2001. These findings are consistent with the idea that people tend to spend more on medical services in the presence of reimbursement insurance. Second, and most importantly, a large increase in medical spending between 1950 and 2001 is observed even when all insurance opportunities are removed. In this case, the share of medical spending increases by 8.9 percentage points, while the actual increase is 8.5 percentage points. Thus, the model suggests that the increase in medical spending during the latter half of the twentieth century is not driven by factors associated with insurance opportunities.[33] Instead, the increase is driven by factors that are common in both economies, namely technological progress in medical treatment and rising incomes. With these two factors alone, the model can explain 63% of the increase in life expectancy at age 25.

When both the price and productivity of medical care are kept constant; i.e., $p_{1950} = p_{2001}$ and $\eta_{1950} = \eta_{2001}$, the share of medical spending is merely 2.3% in 2001. The resulting levels of life expectancy are almost identical to those in 1950.[34] Thus the current model suggests that income growth alone is not enough to explain the observed changes in medical spending and life expectancy.

[32] Consumption expenditures are the sum of spending on consumption good, out-of-pocket expenditures on medical care and spending on private health insurance.

[33] In Hall and Jones (2004), this proposition is taken as given. In the current work, this is formally derived from a dynamic general equilibrium model.

[34] Similar results can be obtained when the experiment is performed in an economy with private insurance only. In this case, the share of medical spending in 2001 is 3.9%, comparing to the benchmark result of 12.4%.

5.3 Robustness

In the first robustness check, different values of the coefficient of relative risk aversion (σ) are considered.[35] In general, a higher degree of risk aversion is associated with a larger demand for insurance and a higher level of medical spending (see Table 9a). The demand for insurance is measured by the per-capita amount of insurance purchased. Algebraically, this is given by

$$\frac{1}{\overline{N}} \sum_{j=0}^{J} \sum_{\boldsymbol{z}^{j-1}} \sum_{\varepsilon \in \mathcal{E}} N\left(\boldsymbol{z}^{j-1}, \varepsilon\right) \widetilde{x}_j\left(\boldsymbol{z}^{j-1}\right).$$

The findings are consistent with the idea that more risk averse agents would like to purchase more insurance. This in turns leads to a higher level of medical spending. An alternative way to assess the change in medical spending in each case is to re-calibrate the productivity of medical care in 1950 (η_{1950}) so as to match the observed share of medical spending in 1950. The results are shown in Table 9b. This exercise illustrates that by adjusting one or more of the undetermined parameters, similar increase in medical spending can be obtained for each value of σ.

In the second robustness check, the price of medical care in 1950 (p_{1950}) is varied. Table 10 shows that the results on medical spending are not sensitive to the choice of p_{1950}. For instance, the share of medical spending reduces from 3.7% to 3.4% when p_{1950} increases from 10 to 20.

6 Concluding Remarks

Two trends are observed during the latter half of the twentieth century. First, there is a persistent rising trend in medical spending. Second, there is a significant increase in life expectancy. The hypothesis examined in this paper is that the combination of technological improvements in medical treatment and rising incomes is the driving force behind these two trends. The backbone of the current analysis is a stochastic, multi-period overlapping-generations model with endogenous survival probability. Agents are *ex post* heterogeneous in terms of the realizations of health shocks. Two market structures with different degrees of insurance opportunity are imposed on this environment. In the first economy, public and/or private health insurance are available via which the consumers can insure against the health shock. In the second economy, agents can only self-insure.

[35] In the 2001 economy, the maximum reimbursement of Medicare (L_g) varies in each case in order to keep the tax rate constant. All other parameters are held constant.

Two things are learned from the quantitative analysis. First, in the presence of technological progress in medical treatment and rising incomes, large increases in medical spending can be obtained in both the benchmark economy and the economy with no insurance. Hence, unlike the previous literature, the current model suggests that the rapid growth in medical spending is *not* due to factors associated with market structures or insurance opportunities. Second, in the current framework technological progress in medical treatment and rising incomes can explain all the increase in medical spending and more than 60% of the increase in average life expectancy during the second half of the twentieth century. This suggests that the rapid growth in medical spending reflects optimal responses to changes underlying the production and accumulation of health.

In mainstream macroeconomic studies, an agent's planning horizon is both fixed and predetermined. The current work is an initial attempt to explore the macroeconomic implications of an endogenous and stochastic planning horizon. Growth in medical spending is just one of the many phenomena associated with a longer lifespan. Intuitively, increases in longevity would have an impact on other life-cycle decisions such as savings, educational choices and retirement. The framework presented in this paper can be extended easily to study these issues.

Appendix A

A1. Medical Spending by Age, 1950-2000

Meara, White and Cutler (2004) estimated the per-person medical spending across age groups for the years 1963, 1970, 1977, 1987, 1996 and 2000. The results, tabulated in their technical appendix, are duplicated in Table A1. This section describes how the estimates for the year 1950 are obtained in this paper. First, it is assumed that over the period 1950-1963, per-person spending in any specific age group had been growing at the same age-specific rate as in 1963-1977. Formally, let $m_{j,t}$ denote the average spending at age j in year t. The age-specific, average annual growth rates (γ_j) between 1963 and 1977 are defined by

$$\left(1+\gamma_j\right)^{14} = \frac{m_{j,1977} - m_{j,1963}}{m_{j,1963}}.$$

Average spending at age j in 1950 is then computed by

$$m_{j,1950} = \frac{m_{j,1963}}{\left(1+\gamma_j\right)^{13}}.$$

The results, labelled as Estimate 1, are reported in Table A1. There are at least two problems with this approach. First, average spending for the elderly (over 65 years of age) is likely to be growing at a higher rate in 1963-1977 than in 1950-1963, due to the implementation of Medicare in 1966. Second, the estimated spending are not increasing in age. In particular, there is a signigicant decrease in medical spending at ages 55-64. As a partial remedy for these problems, an additional assumption is imposed to obtain a second set of estimates. The additional assumption is that average spending for the elderly had been growing at the same rate as that of the 45-54 age group during the period 1950-1963. Algebracially, this implies

$$m_{j,1950} = \begin{cases} \frac{m_{j,1963}}{\left(1+\gamma_j\right)^{13}} & \text{for } j < 45 \\ \frac{m_{j,1963}}{\left(1+\gamma_{45}\right)^{13}} & \text{for } j \geq 45. \end{cases}$$

The resulting estimates are almost constant during ages 45-64 and increases significantly afterwards. Since the second set of estimates exhibits a more reasonable life-cycle pattern, it is used in this paper.

The age-specific medical spending is then weighted using census estimates on the size of the corresponding age group. The results for various subgroups in 1950 and 2000 are reported in Table A2.

Under the second approach, the estimated level of real per-capita spending for the entire population ($432) is closer to that obtained from the aggregate statistics ($448). Also, based on Estimate 2, the growth rate of medical spending among the elderly and the non-elderly are 5.31% and 3.73% respectively.

A2. The Medicare Program

The program is made up of two main parts.[36] Part A, known as the Hospital Insurance program, paid for hospital services. It is universal and mandatory, meaning every person of age 65 or above is automatically enrolled into the program. No premium is required. Its major source of funding has been a payroll tax of 2.9%, which is split between employers and employees. Part B of the program, referred to as the Supplemental Medical Insurance program, provides benefits for physician, out-patient, emergency room and other medical services. Enrollment is voluntary and a monthly premium is required. The intentionally low premium had encouraged over 90% of the enrollees to participate but contributed only a small portion of the revenues. Over the years, the government has subsidized approximately 75% of the total revenues of Part B. The cost sharing structure of the Medicare program is illustrated in Table A5. For the Supplemental Medical Insurance program, all enrollees are subjected to an annual deductible and a coinsurance rate of 20%. As for the Hospital Insurance program, Medicare covers all inpatient hospital expenses for the first 60 days after an annual deductible. For days 61-90, the enrollees only have to pay 25% of the expenses. After day 90, each enrollee can draw on an additional 60-day non-renewable lifetime reserve. During these 60 days, the program covers 50% of the hospital expenses.

[36] In 1997, a third part of Medicare, known as Medicare Advantage Program, was implemented. The objective of this program is to expand the beneficiaries' choices for the supplier of health care.

Appendix B

Proof of Lemma 1

All agents born at time $t \geq 0$ begin their lives with an empty past history of shocks, zero wealth and initial health status $\overline{h}$. The decision rule for consumption at age 0 is thus $c_0\left(\overline{h}, 0, \boldsymbol{z}^{-1}, \varepsilon^0\right) = c_0\left(\boldsymbol{z}^0\right)$, where $\boldsymbol{z}^0 = \varepsilon^0$. The same is true for the other decision rules.

Suppose the lemma is true for age $j = 0, 1, ..., n$, with $n < J$. This means savings and post-treatment health at age n are given by $s_n\left(\boldsymbol{z}^n\right)$ and

$$h_{n+1}\left(\boldsymbol{z}^n\right) = i\left[m_n\left(\boldsymbol{z}^n\right)\right] + \left(1 - \delta_h\right) h_n\left(\boldsymbol{z}^{n-1}\right) + \varepsilon^n,$$

respectively. Then the decision rule for consumption at age $(n+1)$ is

$$c_{n+1}\left[h_{n+1}\left(\boldsymbol{z}^n\right), s_n\left(\boldsymbol{z}^n\right), \boldsymbol{z}^n, \varepsilon^{n+1}\right] = c_{n+1}\left(\boldsymbol{z}^{n+1}\right).$$

The same argument can be applied on the initial old agents. This follows from the fact that they have empty past history of shocks, zero wealth and initial health status $\overline{h}$ at time 0. This completes the proof.

Table 1

Age-specific Death Rates [per 100,000 population for specified group].

	1900	1930	1950	1970	2001
Under 1 year	16245	6900	3299	2142	683
1-4 years	1984	564	139	84	33
5-14 years	386	172	60	41	17
15-34 years	699	395	154	140	93
35-54 years	1216	913	580	523	308
55-64 years	2724	2403	1912	1659	964
over 65 years	8226	7372	6232	5892	5087

Source: Centers for Disease Control and Prevention, National Center for Health Statistics, <http://www.cdc.gov/nchs/about/major/dvs/mortdata.htm>.

Table 2

Death Rates* [per 100,000 population] for Selected Infectious Diseases: 1900-1980.

	1900	1910	1920	1930	1940	1950	1960	1970	1980
Pneumonia and Influenza	202.2	155.9	207.8	102.5	70.3	31.3	37.3	30.9	24.1
Tuberculosis	194.4	153.8	113.1	71.1	45.9	22.5	6.1	2.6	0.9
Typhoid Fever	31.3	22.5	7.6	4.8	1.1	0.1	**	**	**
Diphtheria	40.3	21.1	15.3	4.9	1.1	0.3	**	**	**
Whooping Cough	12.2	11.6	12.5	4.8	2.2	0.7	0.1	**	**
Measles	13.3	12.4	8.8	3.2	0.5	0.3	0.2	**	**

* The reported data are not age-adjusted. This is because age-adjusted mortality rates for some diseases are not available for early years.

** means less than 0.05.

Table 3a

Baseline Parameterization

Demography		
Maximum age	J	15
Retirement age	I	7
Parameters in survival probability function	ψ	0.00112*
	θ	1.892*
Health endowment	$\overline{h}$	100
Population growth rate (5-year)	γ	6.4%
Preferences		
Coefficient of relative risk aversion	σ	0.97
Subjective discount factor (5-year)	β	0.904
Production of Goods		
Capital's share of income	α	0.33
Depreciation rate of physical capital (5-year)	δ_k	0.41
Production of Health		
Relative price of medical care, 1950	p_{1950}	10.0
Relative price of medical care, 2001	p_{2001}	28.8
Productivity of medical care, 1950	η_{1950}	0.274*
Productivity of medical care, 2001	η_{2001}	1.510
Parameter in health production function	ξ	0.10*
Depreciation of health	δ_h	0.065*
Morbidity		
Health shock in "healthy" state	ε_1	0
Health shock in "sick" state	ε_2	−20*

*The values are obtained from the minimization process.

Table 3b

Labor Endowment

	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64
Year 1950	1.00	1.16	1.21	1.22	1.23	1.24	1.20	1.11
Year 2001	2.43	2.98	3.25	3.42	3.54	3.47	3.66	3.37

Table 3c

Probability of Health States

Age	Healthy	Chronic Diseases
25-29	0.997	0.003
30-34	0.996	0.004
35-39	0.991	0.009
40-44	0.984	0.016
45-49	0.974	0.026
50-54	0.958	0.042
55-59	0.936	0.064
60-64	0.909	0.091
65-69	0.876	0.124
70-74	0.845	0.155
75-79	0.821	0.179
80-84	0.801	0.199
85-89	0.789	0.211
90-94	0.763	0.237
95-99	0.732	0.268

Table 4

Selected Real-World Statistics.

1. Share of Medical Spending in GDP, 1950	3.7%
2. Ratio of Medical Spending to Income Among the Non-Elderly, 1950	0.037
3. Ratio of Medical Spending to Income Among the Elderly, 1950	0.117
4. % of Out-of-Pocket Expenditures in Total Medical Spending, 1950	68.3%
5. % of Out-of-Pocket Expenditures in Total Medical Spending, 2001	16.6%
6. Tax rate used to finance Medicare in 2001	2.9%
7. Life Expectancy at age 25 in 1950	47.7
8. Life Expectancy at age 45 in 1950	29.1
9. Life Expectancy at age 65 in 1950	14.3

Table 5

Main Findings from the Benchmark Model.

	Data		Model	
	1950	2001	1950	2001
Share of Medical Spending in GDP	3.7%	12.2%	3.7%	12.4%
Share of Medical Spending in PCE	5.6%	17.3%	4.8%	16.6%
Real Per-capita Medical Spending				
Annual Growth Rate	4.44%*		4.43%	
Medical Spending by Source of Payment				
Out of Pocket	68.3%	16.6%	68.2%	24.7%
Medicare	0%	19.4%	0%	15.5%
Life Expectancy by Age				
Age 25	47.7	54.2	47.7	51.8
Age 45	29.1	35.0	28.9	32.9
Age 65	14.3	18.2	14.7	17.8

* The reported value is the growth rate of real per-capita spending among those aged 25 or above during the period 1950-2000. See Footnote 3 for details.

Table 6

Changes in Life Expectancy between 1950 and 2001.[a]

	Data	Model	% Explained by the Model
Age 25	6.5	4.1	63.1%
Age 45	5.9	4.0	67.8%
Age 65	3.9	3.1	79.5%
Average Life Expectancy[b]			
Measure 1	3.4	2.7	79.4%
Measure 2	5.6	3.7	66.1%
Measure 3	5.4	3.6	66.7%

[a]The reported values are in number of years.

[b]See Footnote 30 for the definitions.

Table 7

A. Ratio of Medical Spending to Income by Age*.

	1950		2001	
	Data	Model	Data**	Model
25-34	0.035	0.033	0.077	0.111
35-44	0.033	0.041	0.074	0.124
45-54	0.040	0.046	0.098	0.134
55-64	0.046	0.043	0.161	0.204
Under 65	0.037	0.040	0.096	0.123
Over 65	0.117	0.105	0.612	0.635

B. Average Annual Growth Rate of Medical Spending by Age.

	Data	Model
25-64	3.81%	4.26%
65-74	5.18%	5.09%
75+	5.28%	6.49%
Over 65	5.41%	5.48%
Over 25	4.44%	4.43%

* See Footnote 29 for details.

**The reported values are for the year 2000.

Table 8

Benchmark Economy vs Economy with No Insurance.

	1950		2001	
	No Insurance	Benchmark	No Insurance	Benchmark
Medical Spending				
% in GDP	2.1%	3.7%	11.0%	12.4%
% in PCE	2.7%	4.8%	14.9%	16.6%
Life Expectancy				
Age 25	47.5	47.7	51.6	51.8
Age 45	28.8	28.9	32.8	32.9
Age 65	14.6	14.7	17.6	17.8

Table 9a

Effects of Changing the Coefficient of Relative Risk Aversion.

Coefficient of Relative Risk Aversion	0.95	0.96	**0.97**	0.98
Benchmark Economy, 1950				
Share of Medical Spending in GDP	2.1%	2.5%	**3.7%**	5.5%
Share of Medical Spending in PCE	2.7%	3.3%	**4.8%**	7.1%
Units of Insurance Purchased	0.016	0.020	**0.028**	0.042
Benchmark Economy, 2001				
Share of Medical Spending in GDP	8.6%	10.1%	**12.4%**	16.9%
Share of Medical Spending in PCE	11.6%	13.6%	**16.6%**	22.5%
Units of Insurance Purchased	0.209	0.254	**0.320**	0.458

Note: The numbers in bold are the baseline results.

Table 9b

Effects of Changing the Coefficient of Relative Risk Aversion.

Coefficient of Relative Risk Aversion	0.95	0.96	**0.97**	0.98
Benchmark Economy, 1950				
Productivity of Medical Care, η_{1950}	0.470	0.380	**0.274**	0.200
Share of Medical Spending in GDP	3.7%	3.7%	**3.7%**	3.7%
Share of Medical Spending in PCE	4.8%	4.9%	**4.8%**	4.9%
Benchmark Economy, 2001				
Productivity of Medical Care, η_{2001}	2.59	2.09	**1.51**	1.10
Share of Medical Spending in GDP	11.8%	12.3%	**12.4%**	13.6%
Share of Medical Spending in PCE	15.8%	16.4%	**16.6%**	18.0%

Note: The numbers in bold are the baseline results.

*The productivity of medical care in 2001 is given by $\eta_{2001} = (1.034)^{51}\, \eta_{1950}$.

Table 10

Effects of Changing the Price of Medical Care in 1950 (p_{1950})

Price of Medical Care in 1950	5	**10**	15	20
Benchmark Economy, 1950				
Share of Medical Spending in GDP	3.9%	**3.7%**	3.5%	3.4%
Share of Medical Spending in PCE	5.2%	**4.8%**	4.6%	4.4%
*Benchmark Economy, 2001**				
Share of Medical Spending in GDP	13.0%	**12.4%**	12.1%	11.9%
Share of Medical Spending in PCE	17.3%	**16.6%**	16.2%	15.9%

Note: The numbers in bold are the baseline results.

*The price of medical care in 2001 is given by $p_{2001} = (1.021)^{51}\, p_{1950}$.

Table A1

Real Per-Person Medical Spending by Age[a]

	1950		1963	1970	1977	1987	1996	2000
	Estimate 1	Estimate 2						
0 to 4 years	104	104	241	550	594	1176	1636	1500
5 to 14 years	133	133	240	336	455	690	1005	1446
15 to 24 years	397	397	574	1046	856	1193	2361	1651
25 to 34 years	502	502	744	932	1139	1382	1746	2351
35 to 44 years	507	507	763	768	1184	1441	2253	2847
45 to 54 years	589	589	942	1087	1562	2309	3042	4045
55 to 64 years	419	590	944	1740	2264	3195	5072	5736
65 to 74 years	434	715	1143	2229	3245	5957	7105	8950
75+ years	563	1184	1895	4309	6996	11325	16253	15503

[a]The reported values are in constant 2001 dollars.

Table A2

Real Per-Person Medical Spending for Selected Age Groups

	1950		2000	Average Annual
	Estimate 1	Estimate 2		Growth Rate**
25-64 years	509	539	3,492	3.81%
over 65 years	475	863	12,053	5.41%
over 25 years	504	584	5,140	4.44%
All Ages	385	432	3,868	4.48%
	(448)	(448)	(4,361)	(4.66%)
Elderly's Share of				
Medical Spending*	13.1%	20.6%	45.1%	
Population*	13.9%	13.9%	19.3%	

Note: The reported values are in constant 2001 dollars. The values in parentheses are per-person values obtained by dividing total personal medical expenditures by the total civilian population.

* These are the elderly's share among those aged 25 and above.

** Average annual growth rate over the period 1950-2001 based on Estimate 2.

Table A3

Age-specific Death Rates [per 100,000 population for each group], 1950

	All Causes	Accident	Suicide	Homicide	Subtotal[a]	Percentage Share[b]
All Ages	936.8	60.6	11.4	5.3	77.3	8.3%
Under 1	3299.2	114.2	0.0	4.4	118.6	3.6%
1 to 4	139.4	36.8	0.0	0.6	37.4	26.8%
5 to 14	60.1	22.7	0.2	0.5	23.4	38.9%
15 to 24	128.1	54.8	4.5	6.3	65.6	51.2%
25 to 34	178.7	45.7	9.1	9.9	64.7	36.2%
35 to 44	358.7	45.7	14.3	8.8	68.8	19.2%
45 to 54	853.9	53.0	20.9	6.1	80.0	9.4%
55 to 64	1901.0	70.8	26.8	4.0	101.6	5.3%
65 to 74	4104.3	116.9	29.6	3.2	149.7	3.6%
75 to 84	9331.1	315.7	31.1	2.6	349.4	3.7%
85 above	20196.9	972.6	28.8	0.0	1001.4	5.0%

Source: Centers for Disease Control and Prevention, National Center for Health Statistics, <http://www.cdc.gov/nchs/data/dvs/mx1950_59.pdf>.

[a] This is the sum of all deaths due to accident, suicide and homicide.

[b] This is the share of deaths due to accident, suicide and homicide in deaths of all causes.

Table A4

Age-specific Death Rates [per 100,000 population for each group], 2001

	All Causes	Accident	Suicide	Homicide	Subtotal[a]	Percentage Share[b]
All Ages	848.5	35.7	10.8	7.1	53.6	6.3%
Under 1	683.4	24.2	0.0	8.2	32.4	4.7%
1 to 4	33.3	11.2	0.0	2.7	13.9	41.7%
5 to 9	15.3	6.4	0.0	0.7	7.1	46.4%
10 to 14	19.2	7.4	1.3	0.9	9.6	50.0%
15 to 19	66.9	32.8	7.9	9.4	50.1	74.9%
20 to 24	95.0	39.5	12.0	17.3	68.8	72.4%
25 to 29	96.2	31.4	12.6	14.9	58.9	61.2%
30 to 34	113.5	28.5	13.0	11.5	53.0	46.7%
35 to 39	165.9	34.1	14.3	10.4	58.8	35.4%
40 to 44	240.5	36.7	15.2	8.6	60.5	25.2%
45 to 49	354.8	36.0	15.7	7.0	58.7	16.5%
50 to 54	512.4	31.9	14.6	5.5	52.0	10.1%
55 to 59	771.8	29.3	14.0	4.4	47.7	6.2%
60 to 64	1,210.7	31.5	12.0	3.5	47.0	3.9%
65 to 69	1,869.7	36.8	12.7	3.3	52.8	2.8%
70 to 74	2,878.3	49.3	13.9	2.5	65.7	2.3%
75 to 79	4,494.0	80.4	16.4	2.5	99.3	2.2%
80 to 84	7,151.9	130.4	18.9	2.5	151.8	2.1%
85 above	15,112.8	276.4	17.5	2.4	296.3	2.0%

Source: Centers for Disease Control and Prevention, National Center for Health Statistics, <http://www.cdc.gov/nchs/data/statab/mortfinal2001_work210R.pdf>.

[a] This is the sum of all deaths due to accident, suicide and homicide.

[b] This is the share of deaths due to accident, suicide and homicide in deaths of all causes.

Table A5

The Cost-sharing Structure of Medicare, selected years

	Hospital Insurance			Supplemental Medical Insurance		
	Day 1-60 (deductible only)	Day 61-90 (coinsurance)	Day 91-150 (lifetime reserve)	Annual Deductible	Coinsurance Rate	Monthly Premium
1966	$40	75%	50%	$50	80%	$3.00
1970	$52	75%	50%	$50	80%	$4.00
1980	$180	75%	50%	$60	80%	$8.70
1985	$400	75%	50%	$75	80%	$15.50
1990	$592	75%	50%	$75	80%	$28.60
1995	$715	75%	50%	$100	80%	$46.10
2001	$792	75%	50%	$100	80%	$50.00

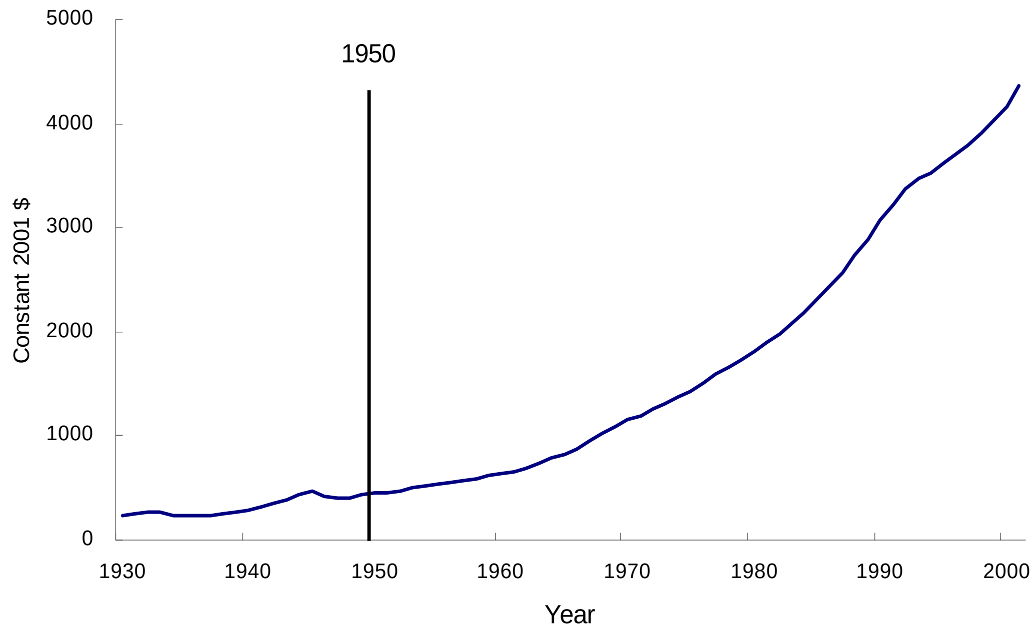

Figure 1: Real Per-capita Personal Medical Expenditures, 1930-2001.

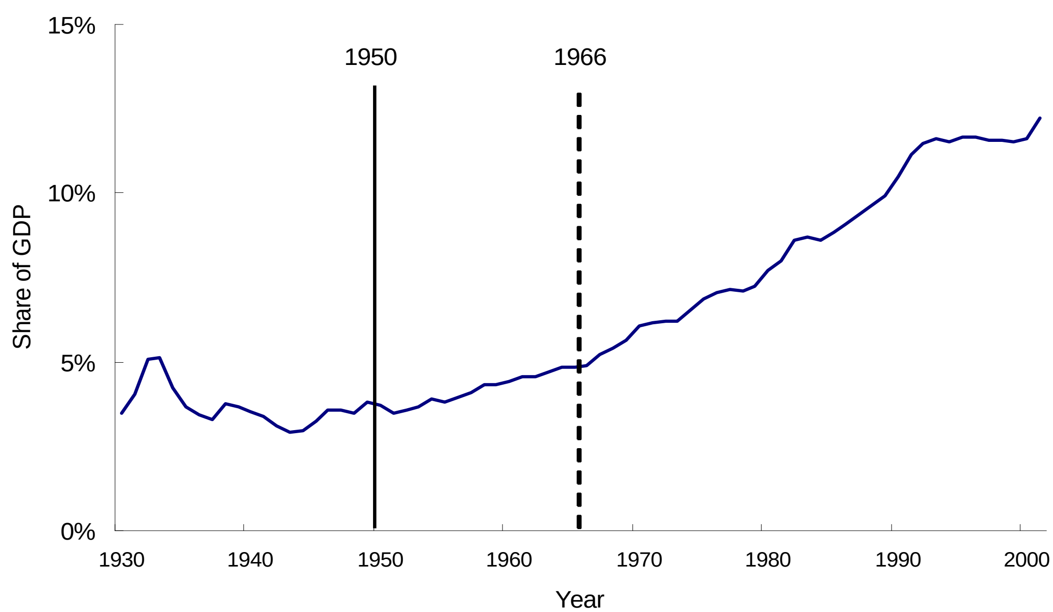

Figure 2: Share of Medical Spending in GDP, 1930-2001.

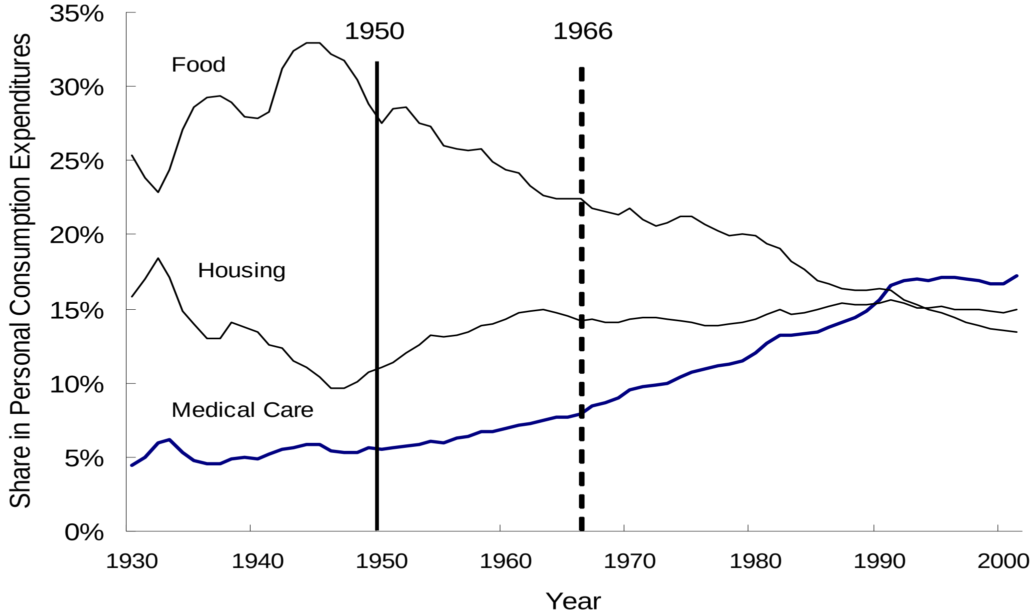

Figure 3: Components of Personal Medical Expenditures, 1930-2001.

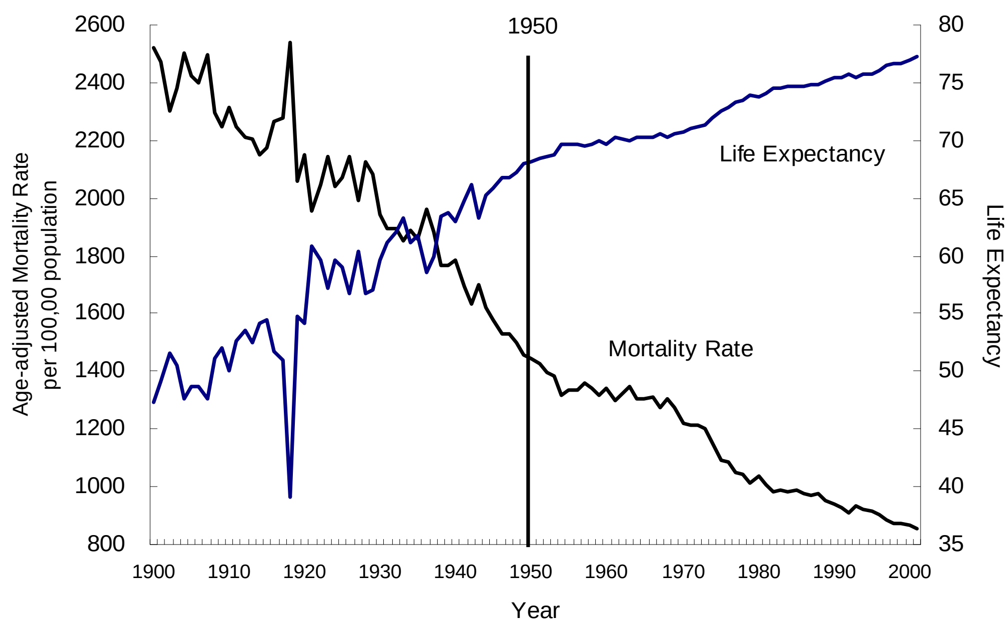

Figure 4: Life Expectancy at birth and Age-adjusted Mortality Rate, 1900-2001.

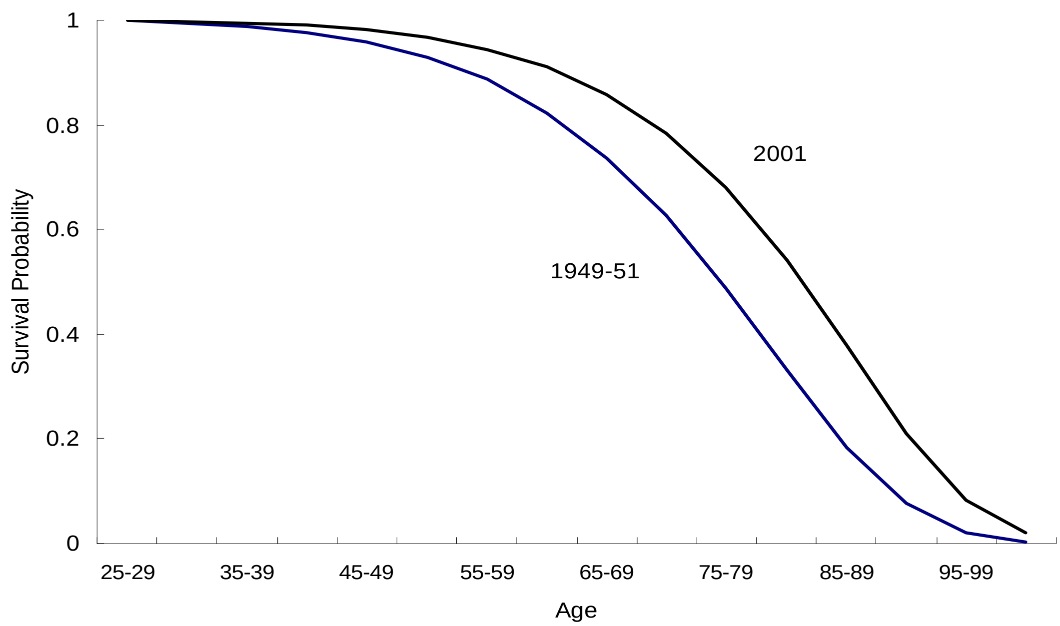

Figure 5: Survival Probability at Age 25 and above, 1949-51 and 2001.

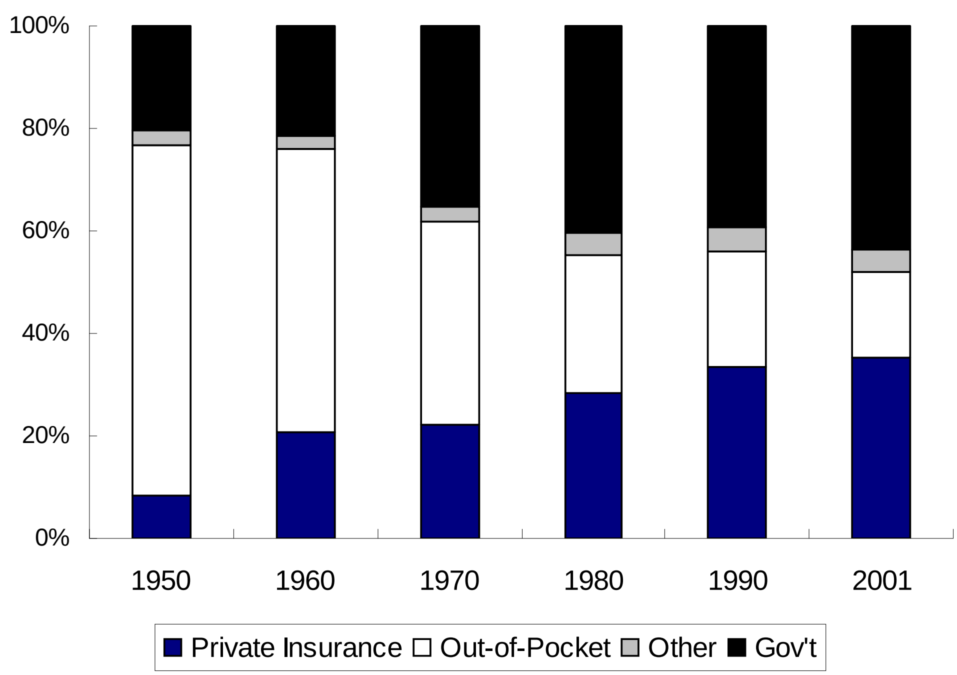

Figure 6: Distribution of Personal Medical Expenditures by Source of Funds, 1950-2001.

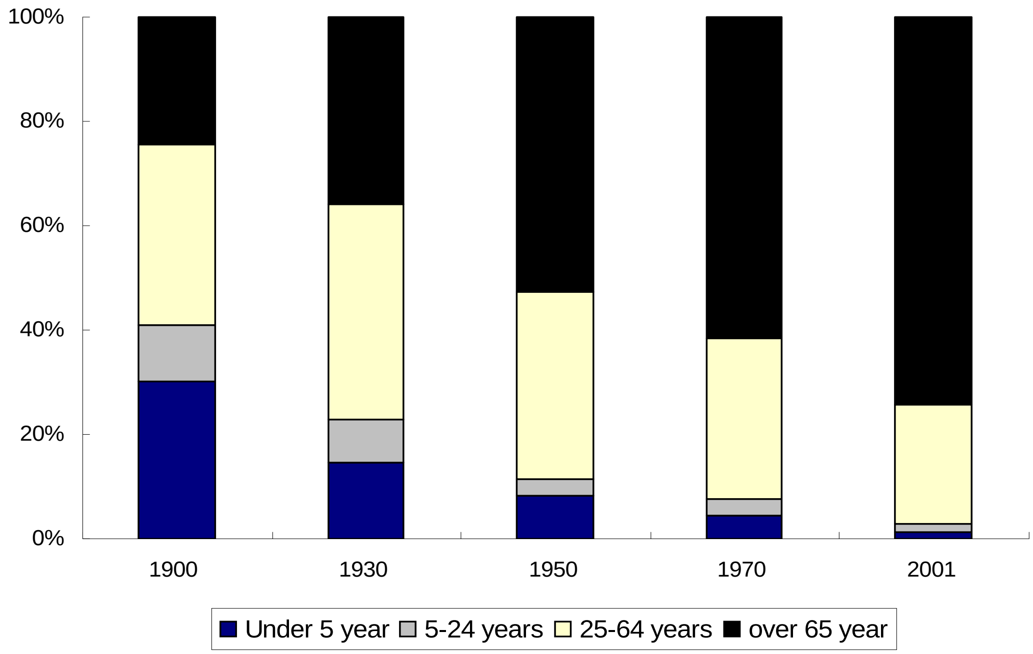

Figure 7: Percentage Distribution of Deaths by Age, 1900-2001.

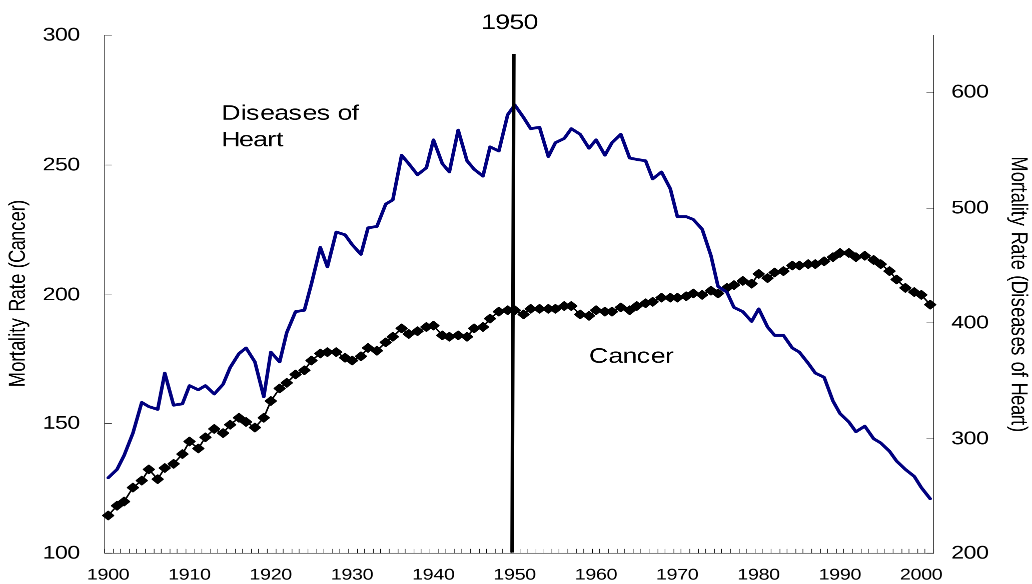

Figure 8: Age-Adjusted Mortality Rates [per 100,000 population] of Diseases of Heart and Cancers.

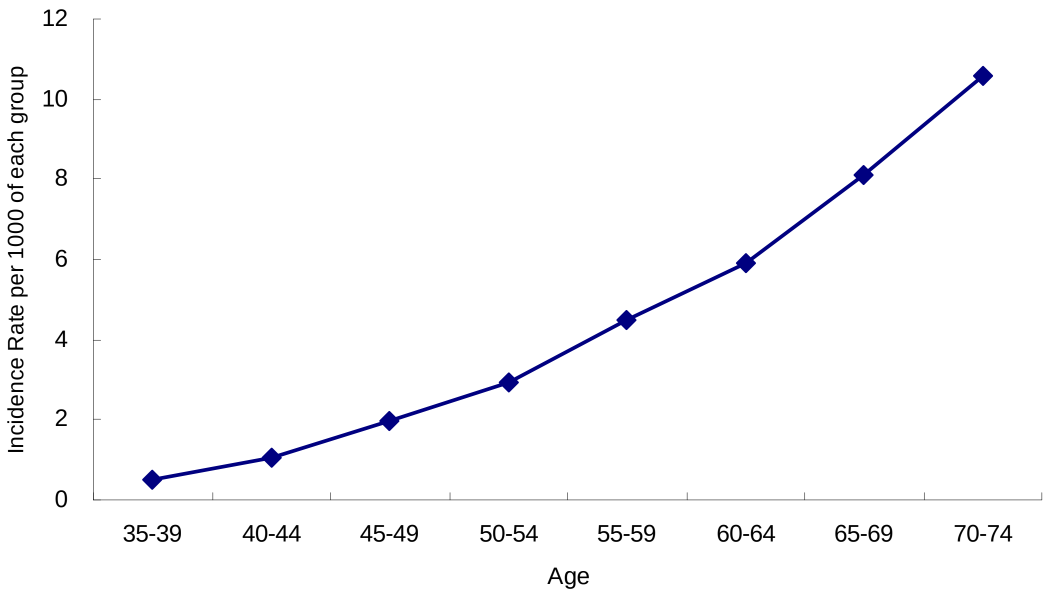

Figure 9: Average Annual Incidence Rate of Coronary Heart Disease, 1987-2000.

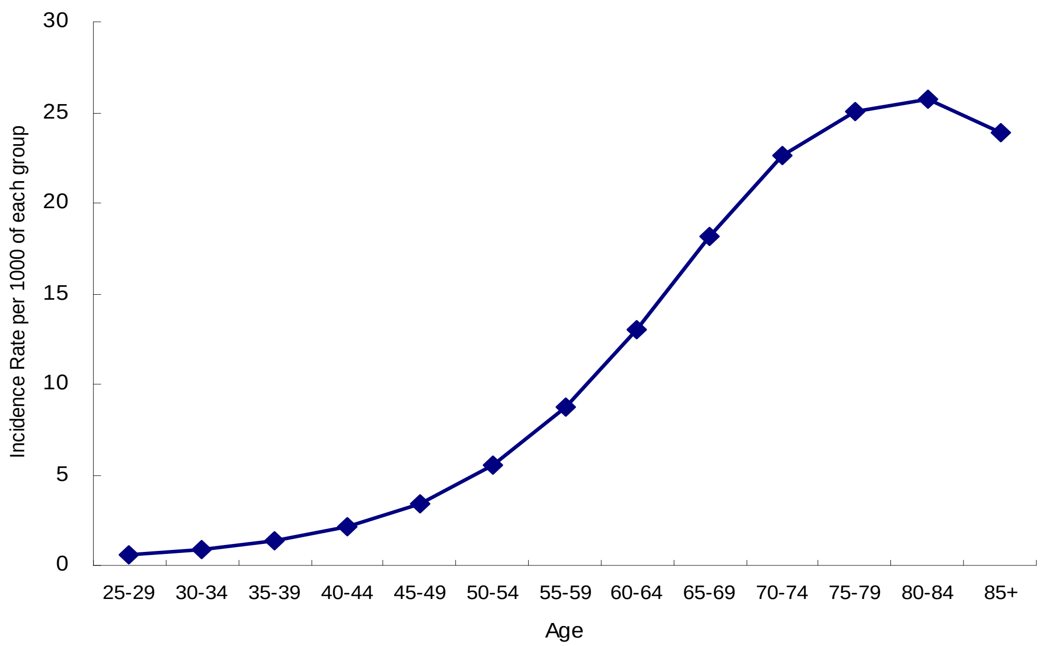

Figure 10: Average Annual Incidence Rate of Cancers, 1989-2001.

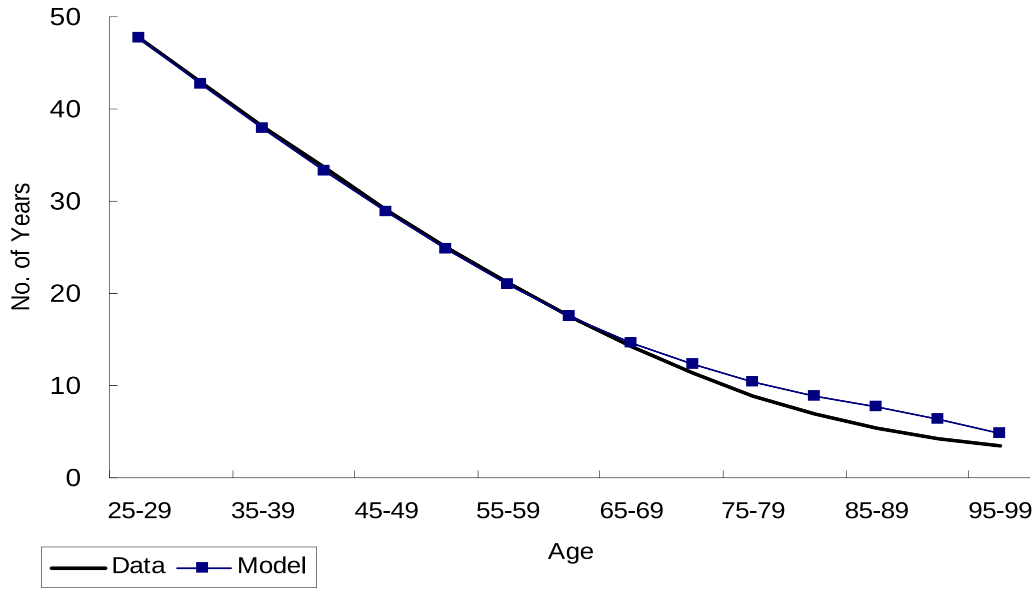

Figure 11: Life Expectancy by Age, 1950.

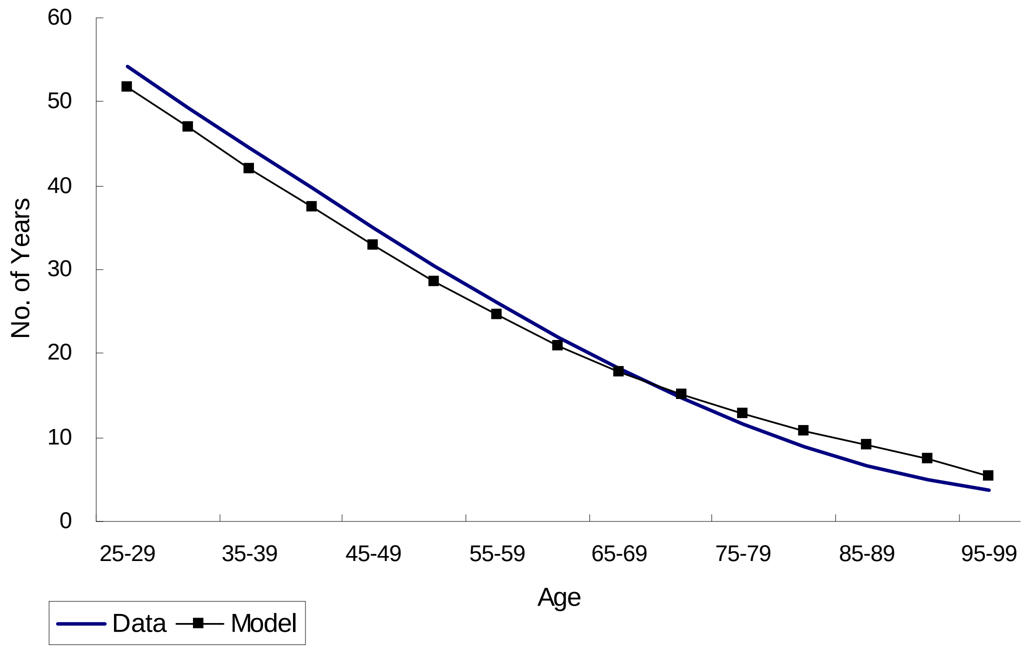

Figure 12: Life Expectancy by Age, 2001.

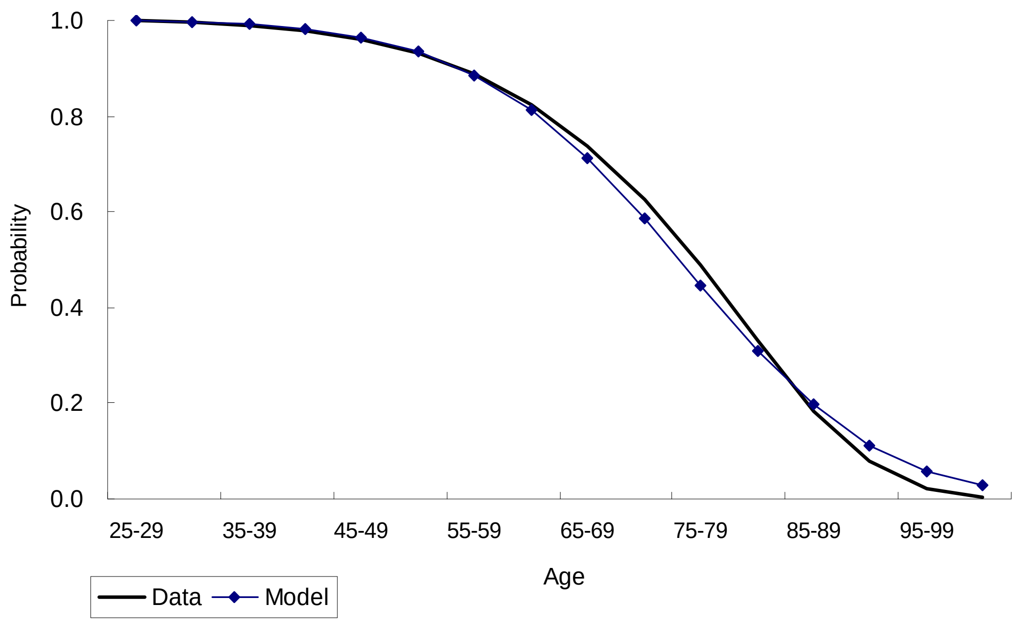

Figure 13: Survival Probabilities in 1950.

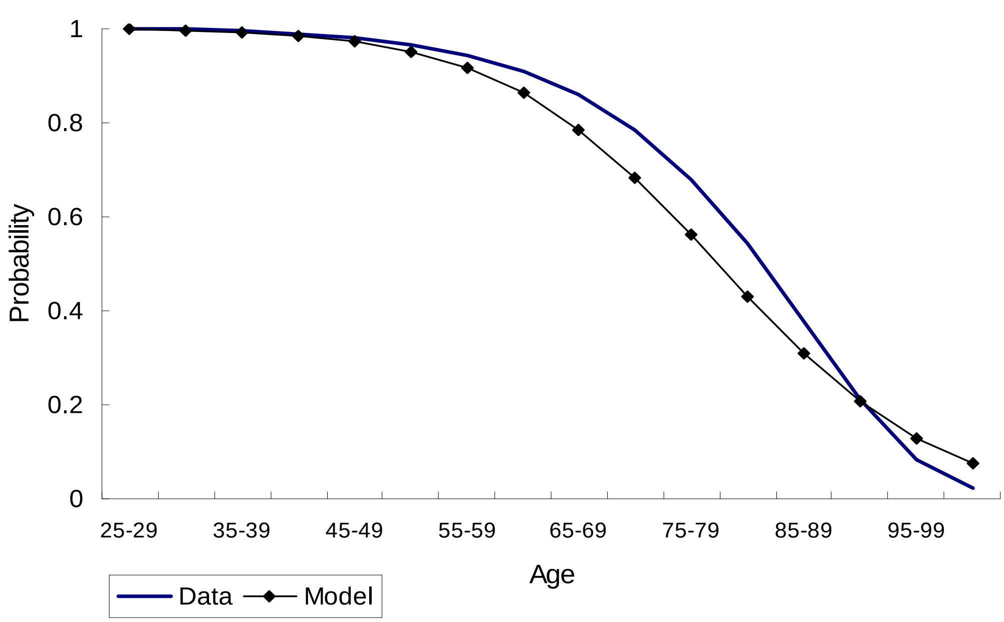

Figure 14: Survival Probabilities in 2001.

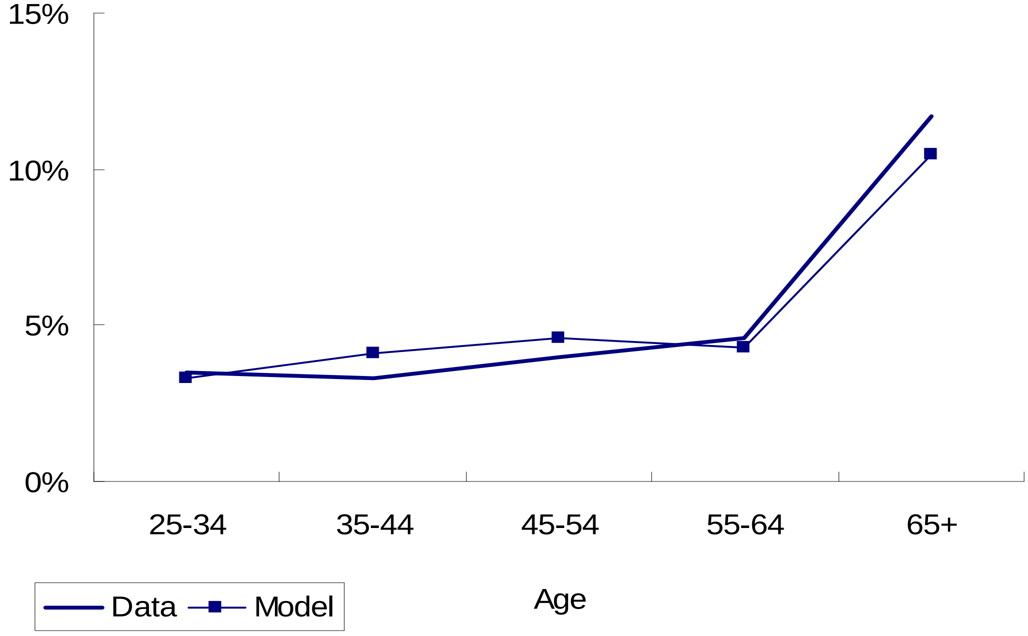

Figure 15: Ratio of Medical Spending to Income by Age, 1950.

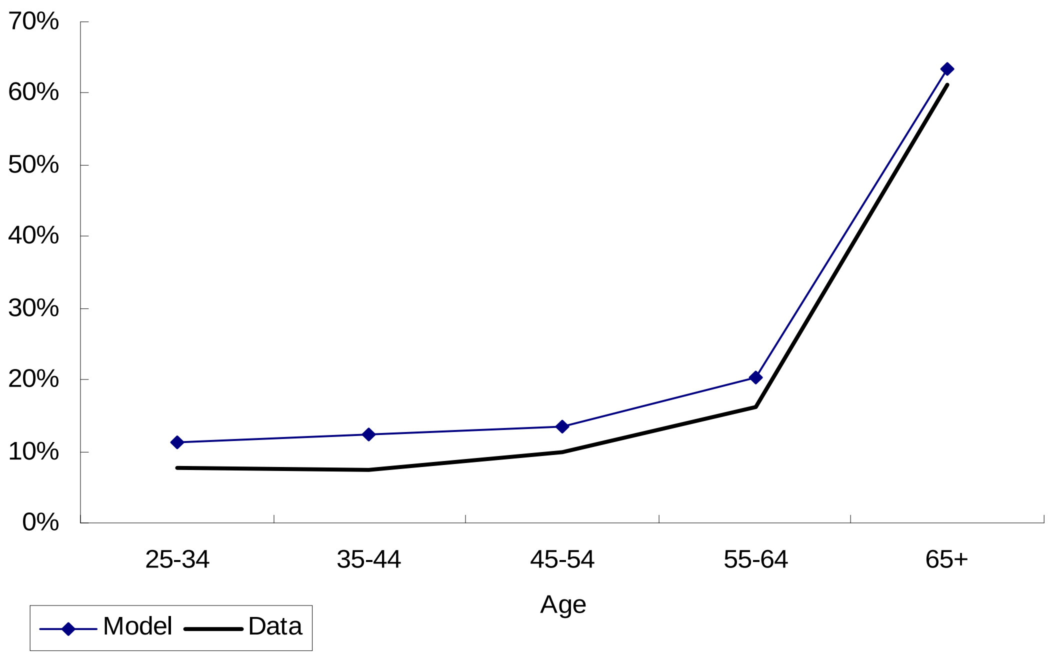

Figure 16: Ratio of Medical Spending to Income by Age, 2001.

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