# Health Spending and Medical Innovation: A Theoretical Analysis

**Toshitaka Fukiharu**

**Abstract** The aim of this paper is to explain an empirical fact by economic models. The fact is that there is a tendency for the share of health spending in GDP to rise. This paper asserts that the fact is partly due to medical innovation. The novelty of models is the explicit incorporation of hospital and doctors who treat patients, with the rise in the parameter of the illness treatment function defined as the medical innovation. Under the monopolistic case, the share always rises, while under the competitive case, it declines for the advanced medical society with a high parameter value; it rises for the basic medical society depending on the ratio between healthy and sick workers, and it rises for the backward medical society with a low parameter value. The theoretical ambiguity of assertion is partly removed by the empirical fact of the monopolistic tendency in the US medical sector. As by-products of this formulation, the emergence of moral hazard and adverse selection is discussed theoretically, where medical insurance—discount of sick workers' medical fee—is procured as a subsidy from healthy workers to them. Moral hazard and adverse selection emerge depending on the parameters of the models.

**Keywords** Adverse selection · General equilibrium · Health spending · Innovation · Moral hazard · Simulation

## 1 Introduction

The advancement of medical technology has contributed to the improvement of human well-being. For example, some of the incurable diseases, such as cancer, have become curable, and the human life expectancy has been lengthened. This enhanced benefit, however, has been accompanied by the enhanced cost. The health spending has steadily increased, and sometimes its growth rate exceeded the one of GDP. Data

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on health spending for 44 countries, including 36 OECD members, reveal that between 2000 and 2017, only two countries reduced their percentage of health spending per GDP (OECD 2020). The USA, the highest spender of GDP on health care, raised its health spending per GDP from 5.542% in 2000 to 14.421% in 2017, which remained the same in 2018 (Pear 2018).

In the present paper, with medical innovation as one of the main culprits in mind, we focus our attention on the reason why national health spending has increased worldwide. For the purpose of examining this problem, Fuchs (1996, p.8) examined whether health economists, economic theorists, and practicing physicians could come to a consensus on the issue: "the primary reason for the increase in the health sector's share of GDP over the past 30 years is technological change in medicine." On this issue, 81% of the health economists agreed with a 99% statistical significance, 37% of the economic theorists agreed with no statistical significance, and 68% of practicing physicians agreed with a 95% statistical significance. From a theoretical viewpoint, Chandra and Skinner (2012) attempted to examine this problem in terms of a two-period partial equilibrium model. Their theoretical model follows the health-capital accumulation approach designed by Grossman (1972) (See also Ehrlich and Yin 2013).

The present paper adopts a different approach. Following Arrow (1963), a one-period general equilibrium model is constructed in which there are two types of households: i.e., the "fortunate" one with 365 working days, and the "unfortunate" one with, say, 300 working days—and the hospital recovers a part of "the lost working days" of the unfortunate households with medical treatment. The households maximize utility subject to the income constraint, where sick households purchase medical services from the hospital. The (aggregate) doctor is nothing but a medical engineer (worker) in the present paper, hired by the hospital with a rental fee. The hospital is a "firm" which supplies the medical service, hiring the doctor and procuring medicines. Along with the hospital, there is another firm, which produces a variety of commodities including medicines, hiring households under profit maximization.

Utilizing this general equilibrium model, the relation between the total health spending per GDP and the medical innovation is examined at first. Medical innovation in the present paper is defined as a shift of the illness treatment function with no modification of cost structure. In terms of the simulation approach, we examine whether the medical innovation raises total health spending for the two models. The first model is the one in which the hospital is a competitive medical service supplier, while the second model is the one in which the hospital is a monopolistic medical service supplier. It must be noted that Arrow (1963) describes the medical sector as "collusive monopoly," and Cutler and Morton (2013) reveal the sector's statistical trend toward a monopoly in the USA.

Next, as a by-product of this approach, we examine the moral hazard and adverse selection problems emerging on the medical insurance. Following the Arrow-type insurance, medical insurance in the form of medical fee deduction is adopted as a subsidy from the "without sickness" households to the "with sickness" households. The present paper is an extension of Fukiharu (2005), which examined the moral hazard under the monopolistic medical sector. The computation was conducted in Fukiharu (2018a, b, c, d).

In Sect. 2 of the present paper, competitive health care market without medical insurance is formulated as the basic model I. After general equilibrium of the model is guaranteed, the effect of the medical innovation on the health spending is derived for the specified parameters. In Sect. 3, monopolistic health care market without medical insurance is formulated as the basic model II. After general equilibrium of the model is guaranteed, the effect of the medical innovation on the health spending is derived for the specified parameters and the comparison with the one in the competitive case is conducted. In Sect. 4, selecting the parameters randomly, the robustness of the conclusion is examined. In Sect. 5, the medical insurance is introduced in the basic models I and II, and the emergence of moral hazard and/or adverse selection is examined. Section 6 concludes these examinations.

## 2 Basic Model I: Competitive Health Care Market

In this section, a general equilibrium model incorporating competitive medical sector is constructed, where medical insurance is not available. It is assumed there are three types of economic agents: "fortunate" and "unfortunate" workers, first and second agents, respectively, and doctors, the third agent. Every worker knows the distribution of workers is constant in each year: $a_1$ workers are fortunate (i.e., with good health), and $a_2$ workers are unfortunate (i.e., without good health). No one knows whether each worker is fortunate or unfortunate before the opening of the particular year. Only when the particular year starts, $a_1$ workers know that they are fortunate, while the remainder know that they are unfortunate. In this sense, each worker has the probability, $\alpha = a_2/(a_1 + a_2)$, of being unfortunate in each year. In this section, it is assumed that $a_1 = 90$ and $a_2 = 10$, and the probability of workers being unfortunate is 10%. This assumption is relaxed later in the robustness analysis.

### 2.1 *Behavior of "Fortunate" Workers*

When a worker is fortunate and healthy, he or she initially has 365 days of leisure days. Their behavior is stipulated by the traditional utility maximization under the income constraint:

$$\max\ u(z_1, le_1) \text{ subject to } p_z z_1 = w(365 - le_1) + Y_1 \tag{1}$$

where $u$ $(z_1, le_1)$ is the utility function, $z_1$ is the consumption of goods, $le_1$ is the leisure consumption, $p_z$ is the price of goods, $w$ is the wage rate, and $Y_1$ is the transfer of income to and from others, such as profit, tax, etc. Since a simulation approach is utilized in this paper, the utility function is stipulated by

$$u(z, le) = z \times le \tag{2}$$

Under (1) and (2), the fortunate and healthy workers' demand function for the goods, $z_{11}$, and the labor supply function, $l_1$, are derived.

## 2.2 Behavior of "Unfortunate" Workers

When a worker is unfortunate, i.e., without good health, he or she has $H_0$ days of initial leisure days, say $H_0 = 300$. He or she goes to a hospital, in order to recover a part of lost leisure days in the year. It is assumed that the hospital can recover $(365–H_0)(1– e^{-s_0 x})$ days of leisure for the sick worker by supplying $x$ medical treatment, employing doctors with a rental price (wage for doctors) $w_D$, and using medicines, while the hospital receives a service charge $p_x$ per one unit of medical treatment, where $s_0$ is the parameter of the "illness treatment function." It is assumed in this section that $s_0 = 1/10$. In Fig. 1, the function $G(x) = (1–e^{-s_0 x})$ is depicted as the straight curve when $s_0 = 1/10$, while it is depicted as the dashed curve when $s_0 = 1/7$: i.e., the medical innovation case.

The unfortunate worker's behavior is stipulated by the following utility maximization under the income constraint:

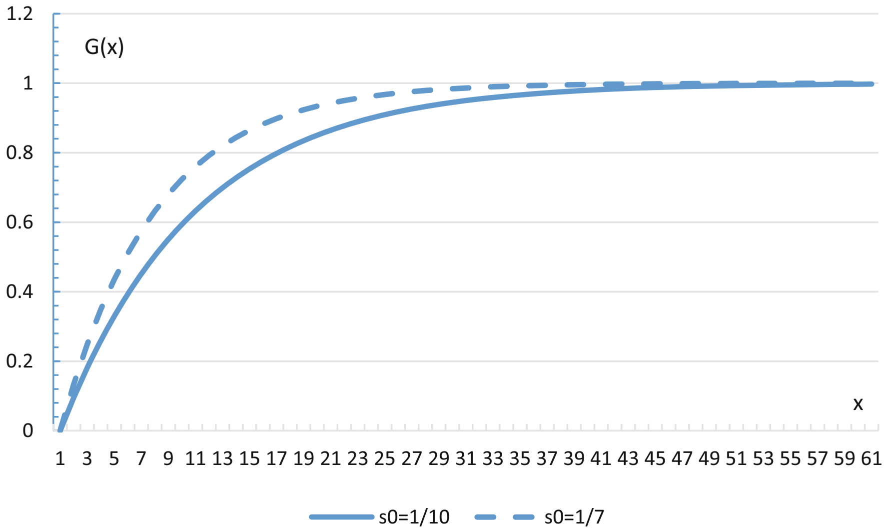


**Fig. 1** $G(x) = \left(1 - e^{(-s_0 x)}\right)$ in the illness treatment function. Source: author's own study

$$\max\ u(z_2, le_2)\ \text{subject to}\ p_z z_2 + p_x x = w(H_0 + (365 - H_0)(1 - e^{-s_0 x}) - le_2) + Y_2 \quad (3)$$

where $u$ ($z_2$, $le_2$) is utility function, $z_2$ is consumption of goods, $le_2$ is leisure consumption, and $Y_2$ is transfer of income to and from others such as profit and tax, etc. In this paper, the simulation approach is utilized with utility function stipulated by (2). Under (2) and (3), the unfortunate household's demand function for the goods, $z_{21}$, the demand function for the medical services, $x_1$, and the labor supply function, $l_2$, are derived analytically, where $H_0 = 300$.

## 2.3 Behavior of Good-Producing Firm

It is assumed that the good-producing firm is under constant returns to labor input. The behavior of this firm is stipulated by profit maximization with production function given by

$$z = f(l_g) = l_g \quad (4)$$

where $z$ is the output of goods and $l_g$ is labor input. The profit maximization under (4) gives rise to $p_z = w$ as one of the conditions for general equilibrium.

## 2.4 Behavior of Hospital and Doctors

The behavior of hospital is stipulated by a "competitive" profit maximization in this section. The production function of medical service is given by

$$x = g(l_x, z_x) = l_x{}^{1/2} z_x{}^{1/2} \quad (5)$$

where $l_x$ is the input of the doctors' working days and $z_x$ is the input of goods (e.g., medicines, etc.). In order to provide the medical service demanded by the sick households, $a_2 \times x_1$, the hospital has the demand function for the doctors, $l_{x1}$, and the one for goods, $z_{x1}$, derived analytically under cost minimization, where cost is denoted by $c = w_D l_x + p_z z_x$ and $w_D$ is the wage (rental price) for the doctors. There are $D_0$ doctors, and each doctor's initial endowment of working days is 365 days.

For simplicity, it is assumed that $D_0 = 1$. The doctor's behavior is the utility maximization under the income constraint:

$$\max\ u(z_D, le_D) \text{ subject to } p_z z_D = w_D(365 - le_D) \tag{6}$$

where $u_D$ ($z_D$, $le_D$) is the utility function, $z_D$ is the consumption of goods, and $le_{\mathrm{D}}$ is the leisure consumption. It is assumed that doctors do not possess the shares of firms. Since the simulation approach is utilized in this paper, the utility function is stipulated by

$$u_D(z_D, le_D) = z_D \times le_D \tag{7}$$

Under (6) and (7), the doctor' demand function for goods and leisure, $z_D$ and $le_D$, are derived analytically. It is shown that $le_D = 365/2$ under (6) and (7).

## 2.5 Competitive General Equilibrium with Competitive Medical Sector

Equilibrium condition for the good-labor market is given by the following equation:

$$a_1 l_1 + a_2 l_2 = a_1 z_{11} + a_2 z_{21} + z_{x1} + z_D \tag{8}$$

Equilibrium condition for the doctors' market is given by the following:

$$l_{x1} = 365 - le_D \tag{9}$$

Utilizing the Newton Method, we can solve competitive medical service charge, $p_{x00,}$ and the rental price of doctor, $w_{D00}$, as follows:

$$p_{x00} = 1.56233$$

$$w_{D00} = 0.6102$$

It is easy to check that in equilibrium, $c$ is indeed equal to $p_x \times a_2 \times x_1$ . Now, the utility level and income for the fortunate worker in this general equilibrium are given by $u_{100}$ and $i_{100,}$ while the utility level and income for the unfortunate worker in this general equilibrium are given by $u_{200}$ and $i_{200}$. The doctor's utility level and income in the competitive general equilibrium are given by $u_{d00}$ and $i_{d00}$. Sum of these utilities in this competitive general equilibrium, the Bentham-type social welfare, is given by $W_{LD00}$, which is computed as follows:

$$W_{LD00} = a_1 u_{100} + a_2 u_{200} + D_0 u_{d00} = 3285378.75344$$

Health spending, $HS_{00}$, defined by $p_{x00}$ $a_2$ $x_1$, and $GDP_{00}$, defined by $a_1 i_{100}$ + $a_2 i_{200}$ + $D_0 i_{d00}$, are computed as follows:

$$HS_{00} = 222.72943$$

$$GDP_{00} = 18394.6$$

Thus, health spending per GDP, $HS_{00}/GDP_{00}$, is approximately 1.2%:

$$HS_{00}/GDP_{00} = 0.01210$$

## 2.6 Medical Innovation under a Competitive Framework

Under this general equilibrium model incorporating a competitive framework, we examine the effect of medical innovation, where medical insurance is unavailable. Medical innovation is defined simply as a shift in "illness treatment function." In this subsection, we assume that medical innovation emerges and $s_0$, the parameter of "illness treatment function," rises from 1/10 to 101/1000. Utilizing the Newton Method, we can solve competitive medical service charge, $p_{x0,}$ and the rental price of doctor, $w_{D0}$, as follows:

$$p_{x0} = 1.55957 < p_{x00}$$

$$w_{D0} = 0.60807 < w_{D00}$$

It is easy to check that in equilibrium, $c$ is indeed equal to $p_x \times a_2 \times x_1$. Now, the utility level and income for the fortunate worker in this general equilibrium are given by $u_{10}$ and $i_{10}$, while the utility level and income for the unfortunate worker in this general equilibrium are given by $u_{20}$ and $i_{20}$. The doctor's utility level and income in the competitive general equilibrium are given by $u_{d0}$ and $i_{d0}$. The sum of these utilities in this competitive general equilibrium, the Bentham-type social welfare, is given by $W_{LD0}$, which is computed as follows:

$$W_{LD0} = a_1 u_{10} + a_2 u_{20} + D_0 u_{d0} => W_{LD00}$$

Health spending, $HS_0$, defined by $p_{x0}$ $a_2$ $x_1$, and $GDP_0$, defined by $a_1 i_{10}$ + $a_2 i_{20}$ + $D_0 i_{d0}$, are computed as follows:

$$HS_0 = 221.94426 < HS_{00}$$

$$GDP_0 = 18394.73771 > GDP_{00}$$

Thus, health spending per GDP, $HS_0/GDP_0$ is approximately 1.2%, lower than $HS_{00}/GDP_{00}$:

$$HS_0/GDP_0 = 0.01207 < HS_{00}/GDP_{00}$$

# 3 Basic Model II: Monopolistic Health Care Market

In this section, the medical sector is assumed to be monopolist. Cutler and Morton (2013) pointed out the trend of monopolization in the US medical sector. For simplicity, we assume that this monopolistic medical sector is owned by the workers with an equal share holding. Thus, monopolistic profit is distributed equally to each worker, whether fortunate or unfortunate. Other assumptions are the same as in Sect. 2, e.g., the good-producing sector is assumed to be a competitive firm. In this modified general equilibrium model, named Basic Model II, we examine the existence of a general equilibrium and a comparison is made with the result in Basic Model I.

## 3.1 Behavior of "Fortunate" Workers, "Unfortunate" Workers, and Good-Producing Firm

We have exactly the same assumptions as mentioned in Sect. 2. Thus, $H_0 = 300$, $a_1 = 90$, $a_2 = 10$, with the same utility functions and the same production functions. From the same computation, we have exactly the same demand functions and supply functions as in Sect. 2. Note that, the hospital's demand functions for the doctor and commodities are derived under the cost minimization.

## 3.2 Behavior of Hospital as a Monopolist and General Equilibrium

We derive the "objective" profit function of the medical sector, OPRO $(p_x)$, which equalizes the demand and supply of the goods and doctors' markets. OPRO $(p_x)$ is derived analytically as follows, from (8) and (9), with $w = 1$, $Y_1 =$ OPRO $(p_x)$/100, $Y_2 =$ OPRO $(p_x)$/100, and $p_z = 1$:

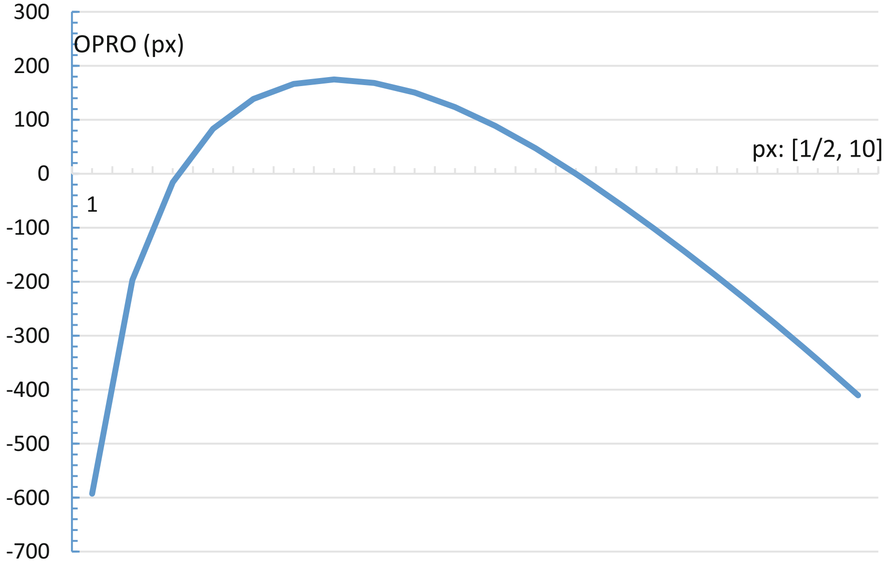


**Fig. 2** OPRO $(p_x)$. Source: author's own study

$$\text{OPRO}\ (p_x) = \frac{100}{73}\left(-73p_x \log\left[\frac{2p_x}{13}\right] + 80\log\left[\frac{2p_x}{13}\right]\sqrt{\log\left[\frac{2p_x}{13}\right]^2}\right)$$

The "objective" profit function of the medical sector, OPRO $(p_x)$, is depicted in Fig. 2.

The monopolistic medical charge by the hospital, $p_{xM00}$, is computed as follows by the Newton Method, which is higher than $p_{x00}$. The wage rate (rental price) of the doctor in the monopolistic medical sector, $w_{DM00}$, is lower than $w_{D00}$.

$$p_{xM00} = 3.51167 > p_{x00}$$
$$w_{DM00} = 0.11382 < w_{D00}$$

Now, the utility level and income for the fortunate worker in this monopolistic general equilibrium are given by $u_{1M00}$ and $i_{1M00,}$ while the utility level and income for the unfortunate worker in this general equilibrium are given by $u_{2M00}$ and $i_{2M00}$. The doctor's utility level and income in the monopolistic general equilibrium are given by $u_{dM00}$ and $i_{dM00}$. The sum of these utilities in this monopolistic general equilibrium, the Bentham-type social welfare, is given by $W_{LDM00}$, which is computed as follows:

$$W_{LDM00} = a_1 u_{1M00} + a_2 u_{2M00} + D_0 u_{dM00} = 3270374.86591 < W_{LD00}$$

The difference between $W_{LD00}$ and $W_{LDM00}$ may correspond with the dead weight loss in the monopoly. Health spending, $HS_{M00}$, defined by $p_{xM00}\, a_2\, x_1$, and $GDP_{M00}$, defined by $a_1 i_{1M00} + a_2 i_{2M00} + D_0 i_{dM00}$, are computed as follows:

$$HS_{M00} = 216.21711 < HS_{00}$$

$$GDP_{M00} = 18290.63351 < GDP_{00}$$

Thus, the "monopolistic" health spending per GDP, $HS_{M00}/GDP_{M00}$, is approximately 1.2%, lower than the "competitive" health spending per GDP, $HS_{00}/GDP_{00}$:

$$HS_{M00}/GDP_{M00} = 0.01182 < HS_{00}/GDP_{00}$$

## 3.3 Medical Innovation under a Monopolistic Framework

As in Sect. 2, medical innovation is defined simply as the shift of "illness treatment function." In this section, we assume that the medical innovation emerges and $s_0$, the parameter of "illness treatment function," rises from 1/10 to 101/1000 as in Sect. 2. By exactly the same procedure as in 3.2, we have the following result.

Utilizing the Newton Method, we can solve the monopolistic medical service charge, $p_{x0M,}$ and the rental price of doctor, $w_{D0M}$ as follows:

$$p_{xM0} = 3.53333 > p_{xM00}$$

$$w_{DM0} = 0.11296 < w_{DM00}$$

It is easy to check that in equilibrium, $c$ is indeed equal to $p_{xM} \times a_2 \times x_1$.

Now, the utility level and income for the fortunate worker are given by $u_{1M0}$ and $i_{1M0}$, while the utility level and income for the unfortunate worker are given by $u_{2M0}$ and $i_{2M0}$. The doctor's utility level and income are given by $u_{dM0}$ and $i_{dM0}$. The sum of these utilities, the Bentham-type social welfare, is given by $W_{LDM0}$, which is computed as follows:

$$W_{LDM0} = a_1 u_{1M0} + a_2 u_{2M0} + D_0 u_{dM0} = 3270622.49894 > W_{LDM00}$$

Health spending, $HSM_0$, defined by $p_{xM0}$ $a_2$ $x_1$, and $GDP_{M0}$, defined by $a_1 i_{1M0}$ + $a_2 i_{2M0}$ + $D_0 i_{dM0}$, are computed as follows:

$$HS_{M0} = 216.72668 > HS_{M00}$$

$$GDP_{M0} = 18116.31366 < GDP_{M00}$$

Thus, health spending per GDP after the medical innovation, $HS_{M0}/GDP_{M0}$ is approximately 1.2%, higher than $HS_{M00}/GDP_{M00}$:

$$HS_{M0}/GDP_{M0} = 0.01196 > HS_{M00}/GDP_{M00}$$

# 4 Robustness

In the previous sections, opposite conclusions were reached on the problem of whether the medical innovation causes the health spending to rise. The competitive framework asserts that it causes a decline in spending, while the monopolistic framework asserts that it causes a rise in spending. These opposite conclusions were obtained with the parameters of the models specified numerically. In this section, through a relaxing of the assumption of specified parameters, we examine how the opposite conclusions vary, where the relaxation does not imply that all the parameters are selected randomly. Thus, in the following sub-subsections, we examine the robustness for the three cases: the *basic* medical society-when $s_0 = 1/10$, the *advanced* medical society-when $s_0 = 10$, and the *backward* medical society-when $s_0 = 1/1000$. The production and utility functions, and so on, are assumed to be exactly the same as in the previous sections.

## 4.1 *Basic Medical Society* ($s_0$ *= 1/10)*

In this subsection, we conduct simulations for the competitive and monopolistic medical sector cases. We start with the competitive case.

### 4.1.1 The Competitive Medical Sector Case

We start from the examination of *the orthodox case* in which $a_1 = 90$ and $a_2 = 10$. In Basic Model I, we derived the health spending when $s_0 = 1/10$ as 222.72943, while the health spending when $s_0 = 101/1000$ was 221.94426: i.e., the medical innovation reduces the health spending for the society. This is the case when there are 80 fortunate workers and 20 unfortunate workers. However, as we move to *the unorthodox*

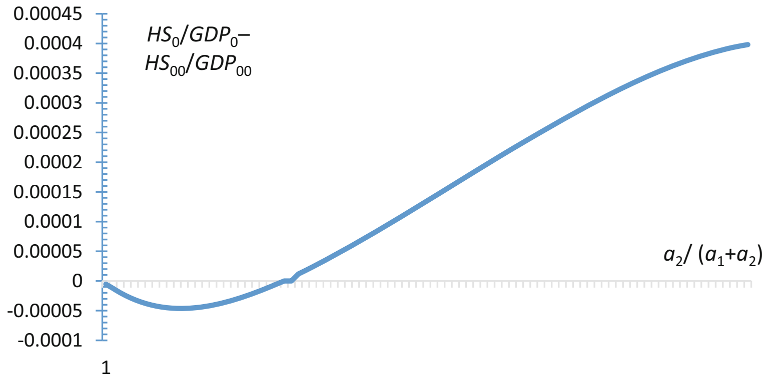


**Fig. 3** $HS_0/GDP_0–HS_{00}/GDP_{00}$ for the basic medical society. Source: author's own study

*case* in which $a_1 = 10$ and $a_2 = 90$, we enter into a different phase. By simulation, when $a_1 = 70$ and $a_2 = 30$, health spending when $s_0 = 1/10$ is 708.10055, while health spending when $s_0 = 101/1000$ is 709.22855: i.e., medical innovation increases health spending for the society. This conclusion holds even when health spending is divided by the GDP. We have the same situation as the society becomes more unfortunate. Thus, we may conclude that the reduction of the health spending per GDP can be realized through the medical innovation only when the society is quite fortunate. Figure 3 reveals this relation, where the horizontal axis indicates the probability of unfortunate worker: $100a_2/\ (a_1+\ a_2)$ and the vertical axis indicates $HS_0/GDP_0–\ HS_{00}/GDP_{00}$.

### 4.1.2 Monopolistic Medical Sector Case

Defining the medical innovation as the shift of "illness treatment function," we examine if the shift of this function can reduce health spending when the medical sector is under a monopoly. Suppose that $s_0$ rises from 1/10 to 101/1000. When $a_1 = 90$ and $a_2 = 10$, the health spending when $s_0 = 1/10$ was 229.41696, while the health spending when $s_0 = 101/1000$ was 229.67466: i.e., the medical innovation raises the health spending for the society. This is the case when $a_1 = 20$ and $a_2 = 90$. The same situation continues until there are $a_1 = 10$ and $a_2 = 90$. Thus, we may conclude that the reduction of health spending cannot be realized through medical innovation under the monopolistic case. This relation holds even when health spending is divided by GDP. Figure 4 reveals this relation, where the horizontal axis indicates the probability of an unfortunate worker: $100a_2/\ (a_1+\ a_2)$ and the vertical axis indicates $HS_{0M}/GDP_{0M}–\ HS_{00M}/GDP_{00M}$.

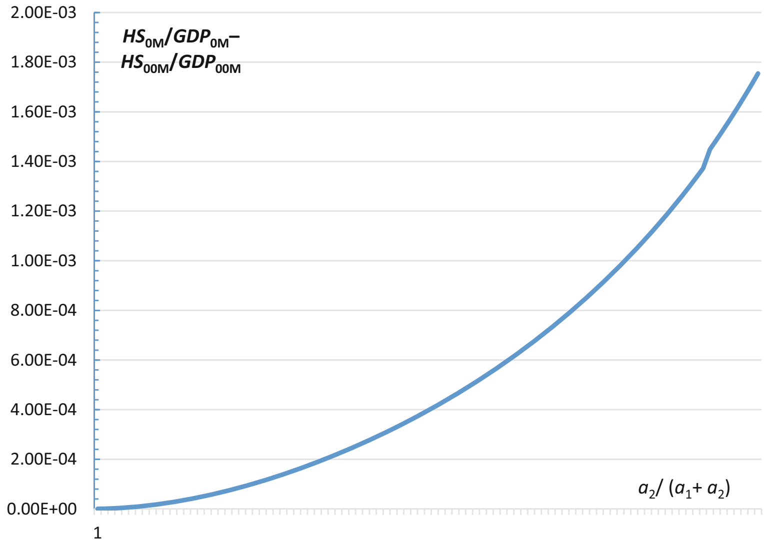


**Fig. 4** $HS_{0M}/GDP_{0M}$–$HS_{00M}/GDP_{00M}$ for the basic medical society. Source: author's own study

## 4.2 *Advanced Medical Society* ($s_0$ = *10*)

The society with a high $s_0$ is named in this paper as the *advanced* medical society. Compared with the *basic* society with $s_0 = 1/10$, we examine how the conclusion in this society differs. Suppose that $s_0 = 10$.

### 4.2.1 Competitive Medical Sector Case

Suppose that $s_0$ rises from 10 to 10 + 1/100. The simulation shows that the health spending declines by the innovation. The conclusion remains the same even if health spending is divided by GDP. Figure 5 reveals this relation, where the horizontal axis $100a_2/(a_1+a_2)$ and the vertical axis indicates $HS_0/GDP_0 - HS_{00}/GDP_{00}$.

### 4.2.2 Monopolistic Medical Sector Case

Under the monopolistic case, suppose that $s_0$ rises from 10 to 10 + 1/100. The simulation shows that health spending rises by the innovation. The conclusion remains the same even if the health spending is divided by GDP. Figure 6 reveals this relation, where the horizontal axis $100a_2/(a_1+a_2)$ and the vertical axis indicates $HS_{0M}/GDP_{0M} - HS_{00M}/GDP_{00M}$.

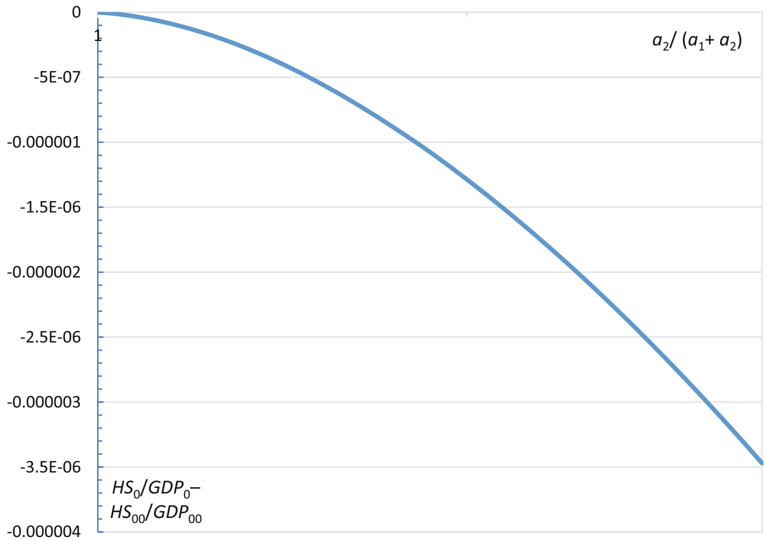


**Fig. 5** $HS_0/GDP_0$–$HS_{00}/GDP_{00}$ for the advanced medical society. Source: author's own study

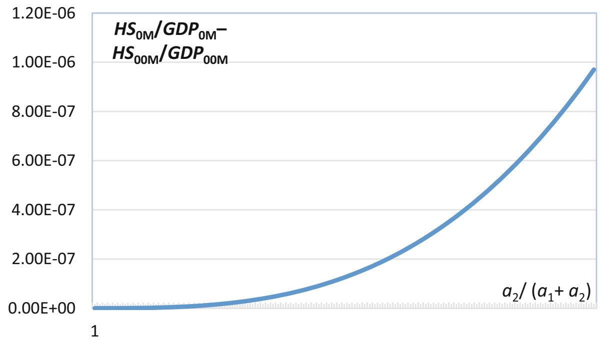


**Fig. 6** $HS_{0M}/GDP_{0M}$–$HS_{00M}/GDP_{00M}$ for the advanced medical society. Source: author's own study

## 4.3 *Backward Medical Society ($s_0$ = 1/1000)*

When $s_0$ is extremely small, we name the society the *backward* medical society. In this section, we examine a *backward* medical society, assuming that $s_0 = 1/1000$.

### 4.3.1 Competitive Medical Sector Case

As in the previous sections, suppose that $s_0$ rises from 1/1000 to 1/1000 + 1/10000. The simulation shows that health spending rises by the innovation. The conclusion remains the same even if health spending is divided by GDP. Figure 7 reveals this

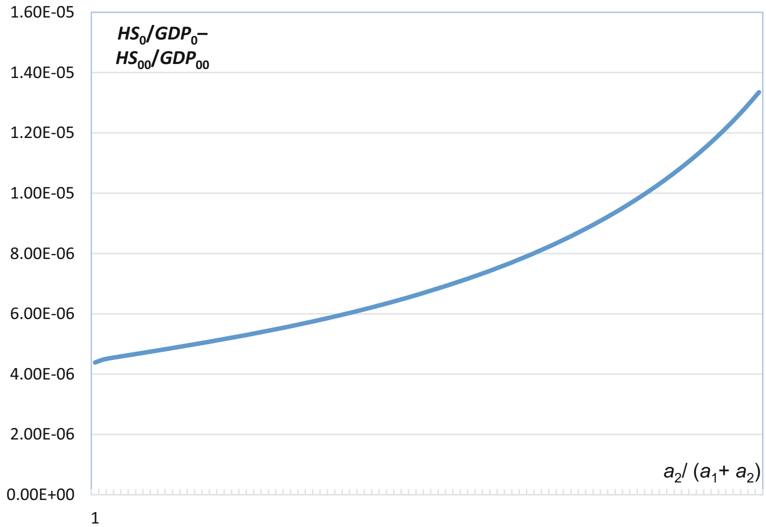


**Fig. 7** $HS_0/GDP_0$–$HS_{00}/GDP_{00}$ for the backward medical society. Source: author's own study

relation, where the horizontal axis indicates $100a_2/(a_1+a_2)$ and the vertical axis indicates $HS_0/GDP_0 - HS_{00}/GDP_{00}$.

### 4.3.2 Monopolistic Medical Sector Case

Under the monopolistic case, suppose that $s_0$ rises from 1/1000 to 1/1000 + 1/10000. The simulation shows that health spending rises by the innovation. The conclusion remains the same even if the health spending is divided by GDP. Figure 8 reveals this relation, where the horizontal axis $100a_2/(a_1+a_2)$ and the vertical axis indicates $HS_{0M}/GDP_{0M} - HS_{00M}/GDP_{00M}$.

The analysis in this section is summarized in Table 1. In the backward medical society in which $s_0$ is low, the health spending per GDP rises by the medical innovation. In the advanced medical society in which $s_0$ is high, the health spending per GDP rises by the medical innovation when the hospital is monopolist while it declines when the hospital is a competitor.

It must be noted that Cutler and Morton (2013) pointed out that the US medical sector has a tendency toward monopoly. Furthermore, Arrow (1963) described the medical sector as the "collusive monopoly." Through the robustness analysis in this section, we may conclude that health spending per GDP tends to rise by the medical innovation.

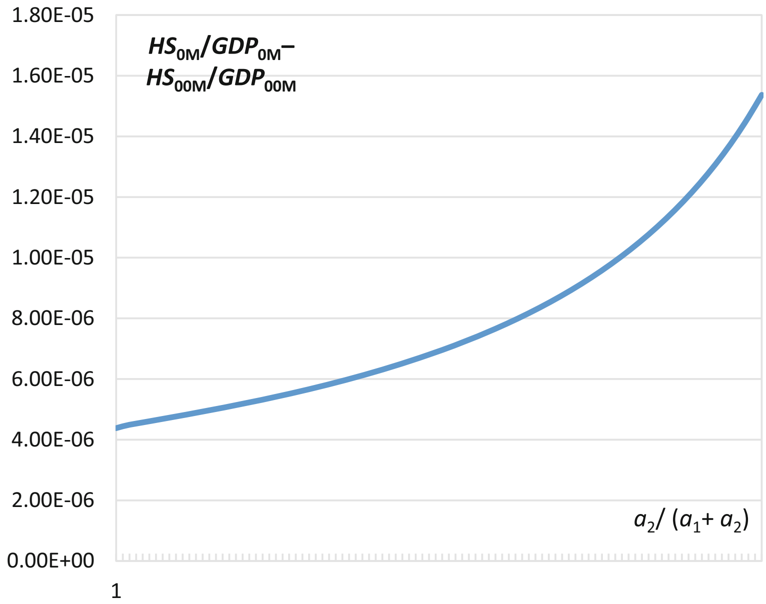


**Fig. 8** $HS_{0M}/GDP_{0M}$–$HS_{00M}/GDP_{00M}$ for the backward medical society. Source: author's own study

**Table 1** Variation of *HS*/*GDP* when the medical innovation emerges

| Medical Society<br>Hospital | Advanced (High $s_0$) | Basic | Backward (Low $s_0$) |
|---|---|---|---|
| Competitor | Decline | Uncertain | Rise |
| Monopolist | Rise | Rise | Rise |

Source: author's own study

# 5 Medical Insurance

As a by-product of the formulation in this paper, we can examine the moral hazard and the adverse selection in the context of general equilibrium.

## 5.1 *Competitive Basic Medical Society* ($s_0 = 1/10$) *under Medical Insurance*

In this subsection, a competitive general equilibrium model incorporating the medical sector is constructed, where medical insurance is available. As in the competitive case, under this medical insurance, 100 *k*% of medical charges on unfortunate and sick workers is deducted by this insurance, while this deduction is made possible by the fortunate workers' insurance premium. Except for this point, the same assumptions are adopted. We start with an orthodox case in which $a_1 = 90$ workers are fortunate and $a_2 = 10$ workers are unfortunate, and the probability, $\alpha = a_2/(a_1 + a_2) = 10/100$, of being unfortunate in each year. As for the general equilibrium model incorporating taxing system, see Fukiharu (2014).

### 5.1.1 Behavior of Agents

When a household is fortunate and healthy, it has 365 days of initial leisure days. Its behavior is stipulated by (1) and (2). Remarks on $Y_1$ are appropriate in this section. We start with the case in which $k = 1/10$. Thus, the deduction cost, divided by the number of fortunate workers, $k\, p_x \times a_2 \times x_1/a_1$ is the transfer payment from the fortunate workers to the unfortunate workers as the health insurance premium. The fortunate worker's demand function for goods, $z_1$, and the labor supply function of healthy worker, $l_1$, are analytically derived. The unfortunate worker's behavior is stipulated by the following utility maximization under income constraint:

$$\max\ u(z_2, le_2) \text{ subject to } p_z z_2 + (1-k)p_x x$$
$$= w(H_0 + (365 - H_0)\,(1 - e^{-x/10}) - le_2) + Y_2 \tag{10}$$

Under (2) and (10), the unfortunate household's demand function for goods, $z_{21}$, the demand function for medical services, $x_1$, and labor supply function, $l_2$, are derived analytically. The behavior of the good-producing firm is stipulated by profit maximization, where production function is given by (4). The profit maximization under (4) gives rise to the equilibrium condition, $p_z = \mathrm{w}$. The behaviors of the hospital and the doctor are exactly the same as in 2.4.

### 5.1.2 Competitive General Equilibrium under Medical Insurance in the Basic Medical Society ($s_0 = 1/10$)

Equilibrium conditions are given by (6) and (7), where $w = p_z = 1$, $Y_1 = -k\, p_x\, a_2\, x_1/a_1$, and $Y_2 = 0$.

Suppose that $s_0 = 1/10$. Utilizing the Newton Method, we can solve competitive medical service charge, $p_{x00k}$, and the rental price of doctor, $w_{D00k}$ as follows:

$$p_{x00k} = 1.63079 > p_{x00}$$
$$w_{D00k} = 0.66487 > w_{D00}$$

It is easy to check that in equilibrium, $c$ is indeed equal to $p_x \times a_2 \times x_1$. Now, the utility level and income for the fortunate worker in this general equilibrium are given by $u_{100k}$ and $i_{100k}$, while the utility level and income for the unfortunate worker in

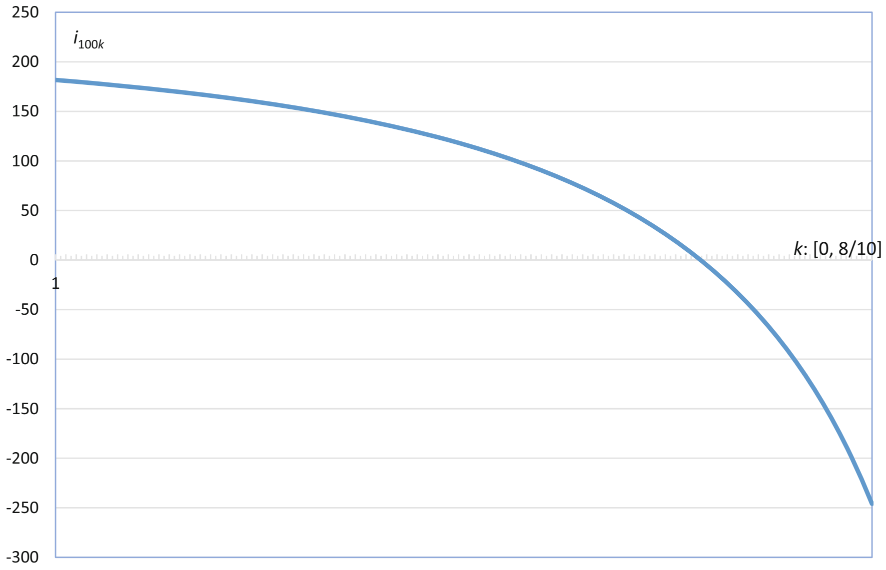


**Fig. 9** Incomes of the fortunate worker, $i_{100k.}$ Source: author's own study

this general equilibrium are given by $u_{200k}$ and $i_{200k}$. The doctor's utility level and income in the competitive general equilibrium are given by $u_{d00k}$ and $i_{d00k}$. The sum of these utilities in this competitive general equilibrium, the Bentham-type social welfare, is given by $W_{LD00k}$, which is computed as follows:

$$W_{LD00k} = a_1 u_{100k} + a_2 u_{200k} + D_0 u_{d00k} = 3285030.48319 < W_{LD00}$$

This result corresponds with the moral hazard argument (Pauly 1968). Next, we examine the moral hazard for the *orthodox* case in which $a_1 = 90$ and $a_2 = 10$ when $k = 2/10, \ldots, 9/10$. The Bentham-type social welfare, $W_{LD00k}$, computed continues to decline until $k = 9/10$. Thus, we may assert that the Pauly-type moral hazard does take place for *the orthodox case*. Finally, we examine the *unorthodox* case in which $a_1 = 10$ and $a_2 = 90$. Note that the competitive general equilibrium with the medical sector is not necessarily guaranteed for the arbitrary medical payment deduction rate, $k$, $0 < k < 1$, since the incomes of the fortunate worker, $i_{100k}$, are negative for $k = 7/10$, 8/10, 9/10, as shown in Fig. 9, in which the $x$-axis indicates $k$, $0 < k < 1$, and the $y$-axis indicates the incomes of the fortunate worker, $i_{100k}$.

In this *unorthodox case*, we compute the Bentham-type social welfare, $W_{LD00k}$, for $k = 0, 1/10, \ldots, 7/10$. When $k = 0$, $W_{D00k} = 2568661.92085$, and it declines until $k = 3/10$. As $k$ increases, however, from $k = 4/10$, and when $k = 5/10$, we have $W_{LD00k} = 2589358.42616$, which is greater than the one when $k = 0$. Thus, near the boundary of $k$, the Pauly-type moral hazard does not emerge. In other words, the social inefficiency does not take place when the government adopts the 50% medical payment deduction rate for this *unorthodox* case.

### 5.1.3 Competitive General Equilibrium under Medical Insurance in the Advanced Medical Society ($s_0 = 10$)

Suppose that $s_0 = 10$. In the advanced medical society, the competitive general equilibrium with the medical sector incorporating medical insurance is guaranteed for arbitrary $k$, $0 < k < 1$ for both the *orthodox* and *unorthodox* cases. Contrary to the basic medical society, the income for the fortunate workers is positive for arbitrary $k$, $0 < k < 1$ in the *unorthodox* case, as shown in Fig. 10.

Utilizing the Bentham-type social welfare, it is confirmed that the moral hazard emerges for both the *orthodox* and *unorthodox* cases: i.e., $W_{LD00k} < W_{LD00}$ for $k = 0$, 1/10, . . ., 9/10.

### 5.1.4 Competitive General Equilibrium under Medical Insurance in the Backward Medical Society ($s_0 = 1/1000$)

First, it is shown that the existence of general equilibrium with medical sector incorporating medical insurance is guaranteed for $k$, $0 < k < 1$, for the *orthodox* and *unorthodox* cases. For the *orthodox* case, we compute the Bentham-type social welfare, $W_{LD00k}$, for $k = 0$, 1/10, . . ., 9/10. When $k = 0$, $W_{LD00k} = 3222597.65517$, and it continues to decline until $k = 9/10$. Thus, we may assert that when the Bentham-type social welfare is adopted, the Pauly-type moral hazard does take place. For the *unorthodox* case, when $k = 0$, $W_{LD00k} = 2358097.67700$, and it declines until $k = 9/10$. Thus, Pauly-type moral hazard takes place.

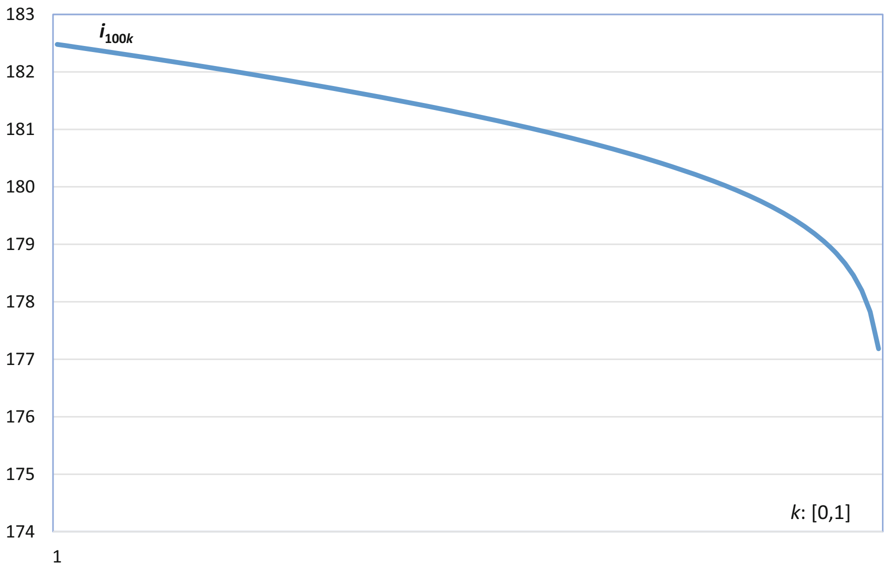


**Fig. 10** Incomes of the fortunate worker, $i_{100k}$. Source: author's own study

## *5.2 Monopolistic Basic Medical Society ($s_0$ = 1/10) under Medical Insurance*

In this subsection, a monopolistic general equilibrium model incorporating medical sector is constructed, where medical insurance is available. Except for this point, the same assumptions are adopted. Thus, the medical insurance is introduced into Basic Model II: i.e., $a_1 = 90$ workers are fortunate and $a_2 = 10$ workers are unfortunate, and the probability, $\alpha = a_2/(a_1 + a_2) = 10/100$, of being unfortunate in each year. By the medical insurance, 100 $k$% of the medical charge of the unfortunate workers is deducted, while the deduction is covered by the insurance premium, paid by the fortunate workers. In this subsection, it is assumed that $k = 1/10$.

### 5.2.1 Behavior of Agents

The behaviors of the "fortunate" and "unfortunate" workers are stipulated by (1) and (10), respectively. The remarks, however, on $Y_1$ and $Y_2$ are appropriate. The hospital, as the monopolist, is owned by the workers with an equal share holding, so that the monopolistic profit is distributed into $Y_1$ and $Y_2$. In order to compute the monopolistic equilibrium under a general equilibrium, the "objective" profit function of the medical sector, $\mathrm{OPRO}_k\,(p_x)$, which equalizes demand and supply in the goods and doctors markets is derived analytically as follows, from (6) and (7), with $w = 1$, $Y_1 = \mathrm{OPRO}_k(p_x)/100 - ka_2p_xx_1/a_1$, $Y_2 = \mathrm{OPRO}_k(p_x)/100$, and $p_z = 1$:

$$\mathrm{OPRO}_k\,(p_x)$$
$$= \frac{5}{146}\left(-2920p_x \log\left[\frac{9p_x}{65}\right] - 1600\log\left[\frac{9p_x}{65}\right]^2 + 1600\log\left[\frac{9p_x}{65}\right]\sqrt{\log\left[\frac{9p_x}{65}\right]^2}\right)$$

### 5.2.2 Monopolistic General Equilibrium under Medical Insurance in the Basic Medical Society ($s_0$ = 1/10)

Suppose that $s_0 = 1/10$. The hospital maximizes $\mathrm{OPRO}_k$ with respect to $p_x$. The monopolistic medical charge by the hospital, $p_{xM00k}$, is computed as follows by the Newton Method, which is higher than $p_{xM00}$ and $p_{x00}$. The wage rate (rental price) of the doctor in the monopolistic medical sector, $w_{DM00k}$, is higher than $w_{DM00}$:

$$p_{xM00k} = 3.82463 > p_{xM00} > p_{x00}$$
$$w_{DM00k} = 0.12133 > w_{DM00}\ (w_{DM00} < w_{D00})$$

Now, the utility level and income for the fortunate worker in this monopolistic general equilibrium are given by $u_{1M00k}$ and $i_{1M00k}$, while the utility level and income for the unfortunate worker in this general equilibrium are given by $u_{2M00k}$ and $i_{2M00k}$. The doctor's utility level and income in the monopolistic general equilibrium are given by $u_{dM00k}$ and $i_{dM00k}$. The Bentham-type social welfare is given by $W_{LDM00k}$, which is computed as follows:

$$\begin{aligned} W_{LDM00k} &= a_1 u_{1M00k} + a_2 u_{2M00k} + D_0 u_{dM00k} \\ &= 3271206.00604 \\ &> W_{LDM00} \end{aligned}$$

The moral hazard does not emerge under the monopoly. The reason $W_{LDM00k}$ is greater than $W_{LDM00}$ stems from the fact that the medical insurance in the present paper is a subsidy in the monopoly. Next, it is shown that the existence of monopolistic general equilibrium with the medical sector is guaranteed for the arbitrary medical payment deduction rate, $k$, $0 < k < 1$, in the *orthodox* case. The non-negativity of $\boldsymbol{i_{100k}}$ is guaranteed. We compute the Bentham-type social welfare, $W_{LDM00k}$, for $k = 0, 1/10, \ldots, 9/10$. When $k = 0$, $W_{LDM00k} = 3274807.59664$, and it continues to rise until $k = 8/10$. While it declines when $k = 9/10$, it is still greater than $W_{LDM00k}$ when $k = 0$. Thus, we may assert that when the Bentham-type social welfare is adopted, the Pauly-type moral hazard does not take place in this case. Finally, it is shown that the existence is not necessarily guaranteed for arbitrary $k$, $0 < k < 1$ when the society is assumed to be of the *unorthodox case*. In this *unorthodox* case, it is impossible to adopt more than a 60% medical payment deduction rate: i.e., $k \geq 6/10$. It is the case, since $i_{1M00k} < 0$, for $k \geq 6/10$. With respect to the moral hazard, we have the following: when $k = 0$, $W_{LDM00k} = 2552288.28913$, and it rises until $k = 5/10$. Thus, the Pauly-type moral hazard does not take place until $k = 5/10$.

### 5.2.3 Monopolistic General Equilibrium under Medical Insurance in the Advanced Medical Society ($s_0 = 10$)

First, it is shown that the existence of monopolistic general equilibrium with the medical sector is guaranteed for the arbitrary medical payment deduction rate, $k$, $0 < k < 1$, in the *orthodox case*. We compute the Bentham-type social welfare, $W_{LDM00k}$, for $k = 0, 1/10, \ldots, 9/10$. When $k = 0$, $W_{LDM00k} = 3291715.71402$, and it continues to decline until $k = 9/10$. Thus, we may assert that the Pauly-type moral hazard takes place in the *orthodox case*. Next, it is shown that the existence of a monopolistic general equilibrium is not necessarily guaranteed for the arbitrary medical payment deduction rate, $k$, $0 < k < 1$ when the society is assumed to be of the *unorthodox* case. In this *unorthodox* case, it is impossible to adopt more than a 60% medical payment deduction rate: i.e., $k \geq 6/10$. Finally, we compute the Bentham-type social welfare, $W_{LDM00k}$, for $k = 0, 1/10, \ldots, 6/10$. When $k = 0$, $W_{LDM00k} = 3012255.33964$, and it rises until $k = 5/10$. Thus, the Pauly-type moral hazard does *not* take place.

### 5.2.4 Monopolistic General Equilibrium under Medical Insurance in the Backward Medical Society ($s_0 = 1/1000$)

First, it is shown that the existence of the monopolistic general equilibrium with the medical sector is guaranteed for the arbitrary medical payment deduction rate, $k$, $0 < k < 1$, in the *orthodox case*. We compute the Bentham-type social welfare, $W_{LDM00k}$, for $k = 0, 1/10, \ldots, 9/10$. When $k = 0$, $W_{LDM00k} = 8901303584456.00296$, and it continues to decline until $k = 9/10$. Thus, we may assert that the Pauly-type moral hazard takes place in the *orthodox case*. Next, it is shown that the existence of the monopolistic general equilibrium is guaranteed for the arbitrary medical payment deduction rate, $k$, $0 < k < 1$ when the society is assumed to be of the *unorthodox* case. We compute the Bentham-type social welfare, $W_{LDM00k}$, for $k = 0, 1/10, \ldots, 9/10$. When $k = 0$, $W_{LDM00k} = 169788593194194090.59993$, and it declines until $k = 9/10$. Thus, the Pauly-type moral hazard does take place in this *unorthodox* case.

## 5.3 *The Adverse Selection*

Akerlof (1970) argued that the market for used cars might disappear due to asymmetric information, providing the dynamic adjustment process toward the disequilibrium, where the sellers of used cars know the quality of them, while the purchasers don't. Rothschild and Stiglitz (1976) asserted that there may not exist (partial) equilibrium in a competitive insurance market with asymmetric information, where the competitive sellers of insurance do not know the exact probabilities of diseases of the purchasers and the insurers must set the insurance fee by the average of those probabilities in a game-theoretic framework. This contribution was extended by Engers and Fernandez (1987), and Dubey and Geanakoplos (2002) in the framework of game theory.

The insurer in the present paper may well be a government, the sole insurer, who attempts to introduce the universal health insurance system. We examined the same non-existence of the market equilibrium under quality uncertainty. In this sense, the adverse selection emerges in the general equilibrium with the medical sector under equilibrium when the insurance system is introduced when the government does not know the probability of health condition of the workers.

# 6 Conclusion

The main aim of this paper was to conduct an examination on the problem of whether the rise of the health spending's share in GDP is caused by medical innovation utilizing general equilibrium models with medical sector. In doing so, a minor aim has been to shed light on the problem of the moral hazard and the adverse selection. In this paper, two types of general equilibrium model were constructed for the purpose of comparison of their conclusions. One of them is the general equilibrium model incorporating medical sector under perfect competition. The other is the one under monopoly.

Independently of the assumption on the competition, there are three economic agents: i.e., fortunate workers, unfortunate workers, and (aggregate) doctor. The numbers of *fortunate* workers with initial labor endowment 365 days and *unfortunate* workers with initial labor endowment $H_0$ days are $a_1$, and $a_2$, respectively. It was assumed that workers do not know whether they are fortunate or not until the beginning of the year. Thus, the probability of workers being *fortunate* is $a_1/(a_1 + a_2)$, and this induces the health care insurance, the deduction of *unfortunate* workers' medical payment through the subsidy by the *fortunate* workers. This insurance follows the idea by Arrow (1963).

The novelty in this paper is the introduction of the "illness treatment function" of the medical sector, with the parameter $s_0$. As $s_0$ rises, it raises the medical sector's ability of treating patients, a measure of medical technology. In this paper, we defined the medical innovation as the rise of $s_0$. The hospital recovers a part of $365–H_0$ with a medical charge. The determination of this medical charge is made either competitively or monopolistically. We compared three types of medical society: the *basic* medical society with $s_0 = 1/10$, the *advanced* one with $s_0 = 10$, and the *backward* one with $s_0 = 1/1000$.

With respect to the medical innovation, its effect on health spending per GDP depends on the level of $s_0$ itself in the competitive case: i.e., when $s_0$ is high (the advanced medical society), the further increase of $s_0$ reduces the health spending per GDP. On the contrary, when $s_0$ is low (the backward medical society), the further increase of $s_0$ raises the health spending per GDP, while in between, the conclusion depends on $a_2/(a_1+ a_2)$. In the monopolistic case, however, the effect of innovation does not depend on the level of $s_0$ itself: i.e., the increase of $s_0$ always raises the health spending per GDP.

In order to reach a conclusion on the problem with respect to the relation between medical innovation and health spending, it may be appropriate to refer to Arrow (1963) and Cutler and Morton (2013). The former describes the medical sector as a "collusive monopoly," whereas the latter pointed out that the US medical sector has a tendency toward monopoly. In consideration of Arrow (1963) and Cutler and Morton (2013), we might be able to assert that the recent rise of health spending in the USA has been, in part, caused by the medical innovation and that there is a causal relation in general between medical innovation and the rise of health spending per GDP.

Utilizing the partial equilibrium analysis, Pauly (1968) argued that the dead weight loss emerges under medical insurance for the health care market with competitive medical sector. On the one hand, in this paper it was shown that the Pauly-type moral hazard emerges in the sense that the Bentham-type social welfare declines under medical insurance for the general equilibrium model with competitive medical sector, except for cases on the boundary. On the other hand, it was shown that the Pauly-type moral hazard does not emerge under medical insurance for the general equilibrium model with monopolistic medical sector in the basic medical society and for the unorthodox cases in the advanced medical society. Akerlof (1970) argued that the market for used cars might disappear due to asymmetric information. In this paper, it was shown that in the sense of the non-existence of the market equilibrium under quality uncertainty, adverse selection may emerge in the general equilibrium with the competitive and monopolistic medical sectors when medical insurance is introduced.

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