National Centre for Epidemiology and Population Health
The Australian National University

Coinsurance Rate Elasticity of Demand for Medical Care in a Stochastic Optimization Model

Alexandra Sidorenko

NCEPH Working Paper Number 45

November 2001

The paper proposes a model of demand for medical care under uncertainty and incorporates an insurance contract with a constant coinsurance rate. Health capital and wealth are modelled as Wiener processes. A theoretical relationship between the coinsurance rate elasticity of the demand for medical care and the coinsurance elasticities of health and wealth is established. Direction and magnitude of change in demand for medical care are shown to depend on the degree of the relative risk aversion with respect to health. Coinsurance rate elasticities of consumption and leisure have also been obtained.

ADDRESS FOR CORRESPONDENCE:
AUSTRALIA-JAPAN RESEARCH CENTRE
THE AUSTRALIAN NATIONAL UNIVERSITY
CANBERRA AUSTRALIA ACT 0200

PHONE: 61 2 6125 3430
PHONE: 61 2 6125 2378 FOR COPY OF PAPER
FAX: 61 2 6125 0767
E-mail: **Alexandra.Sidorenko@anu.edu.au**

* The paper derives from the thesis for PhD degree supported by The Australian National University PhD Scholarship and the Overseas Postgraduate Research Scholarship by the Commonwealth of Australia. The author owes a large debt of gratitude to Warwick McKibbin whose continuous support and advice at different stages of this work was the most helpful. I would like to thank Jim Butler, Adrian Pagan, George Fane, Sugato Bhattacharyya, William Reed, Rhema Vaithianathan, Allen Truslove, Carl Chiarella, Alexander Novikov, participants of the University of Melbourne Economics Seminars; University of Technology, Sydney, School of Finance and Economics Research Seminar Series; participants of the Australian 29th Annual Conference of Economists, and participants of the APSEM Economics PhD Seminar series for their comments on the earlier versions of this paper. Remaining errors are my own.

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Alexandra Sidorenko

Phone: 02 6125-3430
Fax: 02 6125-0767
E-mail: Alexandra.Sidorenko@anu.edu.au

ISBN 0-9579769-1-7

ISSN 1033-1557

Published by the National Centre for Epidemiology and Population Health
The Australian National University
CANBERRA AUSTRALIA ACT 0200

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1. INTRODUCTION

The most widely used theoretical framework for studying the demand for health was pioneered by Michael Grossman in his seminal paper Grossman (1972). Conceptually, health was treated as a durable good - a form of capital different from physical and human capital. Medical care was modeled as one of the inputs into the health production function.

Health capital is different from other forms of human capital in that it determines not just an agent's efficiency in the labor market, but also the total amount of time spent on market activities. It has been recognized that medical care cannot be thought of as being the only determinant of good health. There is an empirical evidence that medical care may be an unimportant determinant of health in developed countries, and there is a lack of positive relationship between good health and medical care on the micro level[1]. Health economists reached a consensus in understanding that medical services are demanded not because of the immediate utility they bring to a consumer, but because of their role in producing "good health", which is of ultimate value.

A number of studies have been devoted to generalization and extension of the Grossman model. Muurinen (1982) used a more general specification for the health capital depreciation rate, allowing it to depend on time and a set of other exogenous variables, including the environmental variables and education. An important paper which contained a critique of Grossman's model was that of Ehrlich and Chuma (1990). Ried (1998) and Jacobson (2000) extended Grossman's model in the deterministic framework. Attempts to incorporate labor supply decision into the Grossman-type model were made by O'Donnell (1995), by including consumption and leisure as arguments of the additive utility function and solving a two-period expected utility maximization problem. Sickness time was assumed to be drawn from a subjectively assessed distribution. The model did not incorporate medical care, and was based on the properties of the distribution of sickness time.

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[1] Grossman (2000) pg. 353.

Following a Kenneth Arrow (1963) paper on uncertainty and economics of medical care, a number of studies were devoted to extension of Grossman model to incorporate uncertainty about health. Stochastic models of demand for health include those of Cropper (1977), Dardanoni and Wagstaff (1987), Dardanoni and Wagstaff (1990), Selden (1993), Picone, Uribe *et al.* (1998), and Ehrlich (2000). None of these studies model insurance against uncertain medical expenditure, or health insurance.

Health insurance provides an individual with a contractual reimbursement of a certain amount up to the total of medical expenses incurred during an episode of illness. In a hypothetical situation of zero-profit operational condition for the insurer and costless provision of the insurance, an actuarially fair premium would equal the expected amount of total reimbursement. Insurance premium loading reflects administrative costs of the insurance company and is equal to the amount over and above the actuarially fair premium charged by the insurer. Cost-sharing instruments used in health insurance contracts include deductibles (fixed contribution by an insured for each claim) and coinsurance (contribution of a certain proportion of the total claim amount). Introduction of deductibles helps reduce the required loading, and also serves as a deterrent to small claims. The insurance contract can also be of indemnity form, providing a specified payment contingent on a certain condition. Insurance contracts often have a specified maximum of benefits payable per accounting period (a year), or provide the consumer with a stop-loss amount (a maximum contribution an insured can expect to pay within a given contractual period). Exclusionary contracts specifically eliminate certain medical procedures from the scope of insurable services. A more detailed discussion of rationale of different health insurance contract instruments is provided in Pauly (1986).

Spence and Zeckhauser (1971) developed a general framework of studying interactions between sequencing of optimal moves taken by individuals and random moves of nature, and information available to the insurer, drawing attention to addressing *ex-ante* and *ex-post* issues separately. The earlier models of medical insurance that cover the individual against uncertain medical expenses have been developed in numerous studies including Zeckhauser (1970), Spence and Zeckhauser (1971), Ehrlich and Becker (1972), Phelps (1973),

Feldstein (1973), Friedman (1974), and the RAND Health Insurance Study, whose results are reported in Newhouse and The Insurance Experiment Group (1993) and in a number of individual papers.

The coinsurance and other price elasticities of the demand for medical care were studied in Phelps (1973), Keeler, Newhouse *et al.* (1977), Phelps and Newhouse (1974), and van de Ven and van Praag (1981). It has been established that demand for medical services is higher at a lower coinsurance rate or a lower deductible, and that the optimal spending strategy under the latter policy option exhibits a non-linear behavior. A study of Phelps and Newhouse (1974) was based upon insurance claims and premiums data. It used the methodology on a total price elasticity of the demand for medical care developed in Phelps (1973). Using their estimates of the total price elasticity, a decrease in the coinsurance rate from 25 percent to zero yielded an estimated 12 percent increase in total medical expenditure. Medical services with a higher time price (waiting time) exhibited relatively higher time price elasticity and a lower price elasticity. Money-price elasticities were found to be decreasing with coinsurance rate.

More recent models of medical insurance include Marquis and Holmer (1996) and Blomqvist (1997). Blomqvist (1997)used a dynamic optimization technique to construct an optimal non-linear health insurance contract with an exogenous income. A paper by Liljas (1998) developed a stochastic model of the demand for health that incorporated insurance against loss of income due to illness. The model was further improved by Tabata and Ohkusa (2000). Modern developments in the theory of health insurance, including optimal insurance contracts, moral hazard and adverse selection are discussed in Cutler and Zeckhauser (2000)].

A new stochastic model of demand for medical care which incorporated both labor supply and insurance has been proposed in Sidorenko (2001). The model is based on the assumption of lognormality of underlying wealth and health distributions. It incorporates a correlation between health and wealth processes without making health a direct function of income as it has been done in Contoyannis and Forster (1999). It is a continuous time model that rests on a probabilistic assumption of lognormality of health justified by previous studies, including Wagstaff and van Doorslaer (1994) and Gerdtham, Johannesson *et al.* (1999).

This paper extends a dynamic stochastic model of demand for medical care and health insurance proposed in Sidorenko (2001). Departures of the present model from Grossman's original framework include no time input into the health production function, and health-adjusted leisure as opposed to the "healthy time" as an argument of the utility function. The latter assumption allows us to model labor supply explicitly and endogenize income. The paper proposes an insurance contract optimal from the consumer's perspective, and derives coinsurance rate elasticity of the demand for medical care, consumption and leisure.

The structure of the paper is as follows: Section 2 contains a brief discussion of the stochastic optimization technique used in Sidorenko (2001), and properties of the model. Section 3 proposes an insurance contract solving for the optimal *ex-post* medical care, consumption and leisure, and *ex-ante* coinsurance rate, assuming that such a contract is offered by the insurance company. Elasticity of control variables with respect to coinsurance rate are derived, and properties are discussed. In particular it has been found that direction and magnitude of change in demand for medical care depends on the degree of the relative risk aversion with respect to health. Section IV concludes.

2. STOCHASTIC MODEL OF DEMAND FOR MEDICAL CARE

Consider a stochastic version of the representative agent model formulated in real terms. The consumer maximizes expected lifetime utility of the stream of consumption and health-adjusted leisure, with the adjustment factor given by $\phi(H_t)$, where $\phi' > 0$, $\phi'' < 0$, and H_t is the current health status measured by a continuous index. Formally the model is stated as finding

$$\max_{c_t, \lambda_t, m_t} E_0 \int_0^\infty U(c_t, \phi(H_t)\lambda_t) e^{-\rho t} dt, \tag{2.1}$$

with respect to consumption c_t, leisure λ_t , and medical expenditure m_t, subject to the dynamic constraints discussed below.

The health capital H_t is assumed to evolve according to the stochastic accumulation equation, with the standard deviation proportionate to the level of health capital and the health depreciation rate given by δ_t. The investment into health capital stock on the interval of the length dt is given by the expression $\psi(m_t)H_t dt$, with $\psi' > 0$, $\psi'' < 0, \psi''' > 0$. The stochastic component is assumed to be a Wiener process, $dh_t \sim N(0, \sigma_H^2 dt)$. Hence, the evolution of health capital is represented by

$$dH_t = (\psi(m_t) - \delta_t)H_t dt + H_t dh_t. \tag{2.2}$$

Another stated variable in the model is wealth. Change in wealth is compounded from the interest earned on the stock of wealth over time dt, plus wage income, less expenditure on the consumption stream and medical care. It is assumed that the unit of labor supplied for the wage-earning activities is paid an "efficiency" wage which depends on the health status of the agent. This allows us to model changes in labor productivity due to changes in the consumer's health. The efficiency coefficient is given by the function $\varepsilon(H_t)$, $\varepsilon' > 0$, $\varepsilon'' < 0$. The error term enters multiplicatively in W_t, similar to what is postulated by the health accumulation equation. The real price of medical services in terms of consumption good is given by χ_t. The stochastic wealth accumulation equation is given by

$$dW_t = (r_t W_t + \omega_t \varepsilon(H_t)(1-\lambda_t) - c_t - \chi_t m_t)dt + W_t dw_t, \tag{2.3}$$

where ω_t is a wage rate, r_t is a real interest rate, and $dw_t \sim N(0, \sigma_W^2 dt)$ is a Wiener process for wealth disturbances. The instantaneous covariance between the two disturbances is given by $\mathrm{cov}(dh_t, dw_t) = \sigma_{HW} dt$. The initial values for stocks of health and wealth are given by H_0 and W_0 respectively.

An expected utility maximization problem (2.1) subject to two stochastic accumulation equations (2.2), (2.3) has been solved in Sidorenko (2001). The paper studied a case of a self-insured consumer, and introduced an insurance contract with a constant coinsurance rate. It

has been demonstrated that availability of insurance leads to changes in the optimal solution: the marginal evaluation of health decreases, and the optimal stock of health increases in presence of insurance. An increase in the optimal consumption of medical care after the introduction of insurance has been illustrated by computer simulations. Insurance contract in Sidorenko (2001) is unsustainable – the insurance company will soon run into liquidity problem, and premium-setting rule has to be re-assessed.

This paper proposes an alternative health insurance contract and studies changes in demand for medical care in response to changes in coinsurance rate, by deriving the relevant elasticity. The paper uses stochastic optimization technique[2] which can be outlined as follows. For the stochastic process dy generated by the equation $dy = f(y,t)dt + dv$, where $dv \sim N(0,\Sigma(y,t)dt)$, a stochastic differential of the function $G(y,t)$, twice differentiable in its arguments, is given by the Itô's Lemma:

$$dG = G(y(t+dt),t+dt) - G(y(t),t) = \frac{\partial G}{\partial t}dt + (\frac{\partial G}{\partial y})'dy + \frac{1}{2}(dy)'\frac{\partial^2 G}{\partial y \partial y'}dy + o(dt) =$$
$$= \left[\frac{\partial G}{\partial t} + (\frac{\partial G}{\partial y})'f + \frac{1}{2}tr(G_{yy}\Sigma)\right]dt + (\frac{\partial G}{\partial y})'dv$$

where tr stands for the trace of a matrix.

A differential generator of *G(y,t),* denoted by $L_y[G(y,t)]$ and defined as the expected rate of change in *G(y(t),t),* is given by

$$L_y[G(y,t)] = \lim_{dt \to 0} E_t\left[\frac{dG}{dt}\right] = \frac{\partial G}{\partial t} + (\frac{\partial G}{\partial y})'f + \frac{1}{2}tr(G_{yy}\Sigma).$$

The stochastic control problem is formulated as finding $\max_{x_s} \tilde{V}(y(0),0) = E_0 \int_0^\infty U(y(s),x(s),s)ds$,

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[2] See Turnovsky (1995) Chapter 14, Malliaris and Brock (1982) Chapter 2.

subject to stochastic accumulation equation $dy = f(y,t)dt + dv$ for the state variable y_s (x_s is a control variable). The stochastic Bellman equation has to be satisfied at the optimum:

$$0 = \max_{x_s}\{U(y(t), x(t), t) + L_y[\tilde{V}(y(t), t]\},$$

where the control variables x_s satisfy their first-order optimality conditions. Value function $\tilde{V}(y(t), t)$ is defined by $\tilde{V}(y(t), t) = \max_{x_s} E_t \int_t^{\infty} U(y(s), x(s), s)ds$.

This technique is applied to solve the two-stage problem of choosing the optimal insurance contract by a utility-maximizing consumer discussed in the following section.

3. OPTIMAL INSURANCE CONTRACT

Consider a stochastic version of the representative agent model formulated in Section 2, and suppose that there is an insurance contract offered to the consumer on following terms. The consumer is liable for part of her medical spending, that is, the insurance contract includes a positive coinsurance parameter, *k*. An insurance premium is paid at time *t*, and medical spending is incurred over the interval *(t, t+dt)*, of which a fraction *k* is paid by the insured. The question of how the insurance company is financed is not addressed explicitly. Premium flow charged by the insurance company at time *t* was considered to be given by actuarially fair $\pi_t = (1-k)\chi \lim_{dt \to 0} E_t \frac{dm_t}{dt}$ in Sidorenko (2001), and can be generalized to include a positive loading. An appropriate stochastic wealth accumulation equation now is given by

$$dW_t = (r_t W_t + \omega_t \varepsilon(H_t)(1-\lambda_t) - c_t - \pi_t - k\chi_t m_t)dt + W_t dw_t, \tag{2.3'}$$

where ω_t is a wage rate, r_t is a real interest rate, and $dw_t \sim N(0, \sigma_W^2 dt)$ is a Wiener process for wealth disturbances. The rest of the assumptions are identical to those of Section 2.

A choice of optimal insurance contract from the consumer's perspective is modeled as a two-stage procedure which combines choosing the optimal coinsurance rate *ex-ante*, and optimal medical expenditure, consumption and leisure *ex-post*, after the shocks to health and wealth were realized. This approach follows Phelps (1973), who applied it to model an insurance which transfers income from the good state of the world to the sick state, with additive health shock drawn from a continuous distribution. The Phelps's model is a one-period model which extended an earlier model of Ehrlich and Becker (1972).

Consider the problem when both premium π and a coinsurance rate k are given to the consumer at the onset of the interval [*t, t+dt*). Insurance premium will depend on the coinsurance rate, and characteristics of the consumer, and not on the *ex-post* medical expenditure over (*t, t+dt*): $\frac{\partial \pi_t}{\partial m_t} = 0$.

3.1. Consumer Optimization Problem

Consolidating the model, the consumer is optimising the expected utility of the stream of consumption and health-adjusted leisure:

(3.1) $$\max_{c_t, \lambda_t, m_t} E_0 \int_0^\infty U(c_t, \phi(H_t)\lambda_t) e^{-\rho t} dt,$$

with respect to consumption c_t, leisure λ_t, and medical care m_t, subject to

(3.2) $$dH_t = (\psi(m_t) - \delta_t) H_t dt + H_t dh_t,$$

(3.3) $$dW_t = (r_t W_t + \omega_t \varepsilon(H_t)(1-\lambda_t) - c_t - \pi_t - k\chi_t m_t) dt + W_t dw_t,$$

where

$dh_t \sim N(0,\sigma_H^2 dt)$, $dw_t \sim N(0,\sigma_W^2 dt)$, $\mathrm{cov}(dh_t, dw_t) = \sigma_{HW} dt$. It is assumed that $\phi' > 0$, $\phi'' < 0$, $\varepsilon' > 0$, $\varepsilon'' < 0$, and $\eta_\varepsilon = \eta_\phi = \eta < 0$ - a constant elasticity of $\phi(\cdot)$, $\varepsilon(\cdot)$ with respect to H, defined as $\eta_\phi = -H\dfrac{\phi'(H)}{\phi(H)}$ and $\eta_\varepsilon = -H\dfrac{\varepsilon'(H)}{\varepsilon(H)}$.

To maximize (3.1) subject to two stochastic accumulation equations (3.2), (3.3) we will apply the stochastic optimization technique discussed in Section 2 for $y_t = (H_t, W_t)'$ and $x_t = (c_t, \lambda_t, m_t)'$.

The value function is assumed to be of the form similar to the integrand in the utility functional:

$\tilde{V}(H,W;t) = V(H,W,t)e^{-\rho t}$, and its differential generator is given by

$$L_y[\tilde{V}(y(t),t)] = \frac{\partial \tilde{V}}{\partial t} + \frac{\partial \tilde{V}}{\partial H}(\psi(m_t) - \delta_t)H_t + \frac{\partial \tilde{V}}{\partial W}(r_t W_t + (1-\lambda_t)\omega\varepsilon(H_t) -$$
$$- c_t - \pi_t - \chi_t m_t) + \frac{1}{2}\frac{\partial^2 \tilde{V}}{\partial H^2}H^2\sigma_H^2 + \frac{\partial^2 \tilde{V}}{\partial H \partial W}HW\sigma_{HW} + \frac{1}{2}\frac{\partial^2 \tilde{V}}{\partial W^2}W^2\sigma_W^2$$

To simplify notations, the time index is dropped, and subscripts will be used to denote partial derivatives with respect to the relevant variable.

Consider

(3.4) $$H = e^{-\rho t}U(c,\phi(H)\lambda) + L_y[\tilde{V}(H,W;t)] =$$

$$= e^{-\rho t}U(c,\phi(H)\lambda) + V_t e^{-\rho t} - \rho\tilde{V} + \tilde{V}_H(\psi(m) - \delta)H +$$
$$+ \tilde{V}_W(rW + \omega\varepsilon(H)(1-\lambda) - c - \pi - k\chi m) +$$
$$+ \frac{1}{2}\tilde{V}_{HH}H^2\sigma_H^2 + \tilde{V}_{HW}HW\sigma_{HW} + \frac{1}{2}\tilde{V}_{WW}W^2\sigma_W^2.$$

Maximising (3.4) with respect to c_t, λ_t, m_t, and treating the premium and the coinsurance rate as fixed, the first order necessary conditions for the optimal choice of controls are

(3.5.a) $$U_c(c,\phi(H)\lambda) = V_W,$$

(3.5.b) $$U_\lambda(c,\phi(H)\lambda)\phi(H) = \omega V_W \varepsilon(H),$$

(3.5.c) $$V_H \psi'(m)H = k\chi V_W$$

Expression (3.5.a) is a standard condition equating the marginal cost of reducing current period consumption by one unit to the marginal benefits of having an extra unit of wealth available. Condition (3.5.b) states that the health-adjusted utility gain from the additional unit of leisure is equal at the optimum to the efficiency-adjusted loss of an extra unit of time spent on wage-earning activities. The third condition (3.5.c) states that the gain in terms of the value of health of the marginal product of the unit of medical expenditure in the production of new health must be equal to the marginal loss of $k\chi$ units of wealth, where χ is a price per unit of medical care and k is a consumer's coinsurance rate. These are standard and intuitive interpretations of the first order conditions (3.5).

In addition, the Bellman equation has to be satisfied when the optimal values from (3.5) are substituted, which in this case is equivalent to

(3.6)

$$0 = \max_{c,\lambda,m} \{U(c,\phi(H)\lambda) - \rho V + V_t + V_H(\psi(m) - \delta)H + V_W(rW + \omega\varepsilon(H)(1-\lambda) - c - \pi - k\chi m) + \\ + \frac{1}{2}V_{HH}H^2\sigma_H^2 + V_{HW}HW\sigma_{HW} + \frac{1}{2}V_{WW}W^2\sigma_W^2\}$$

The solution of the optimality conditions (3.5.a-c) are functions of H, W, and t, that is

$c = c(H, W, t)$, $\lambda = \lambda(H,W,t)$, and $m = m(H, W, t)$.

The partial derivatives of the value function are of the form $V_H = V_H(H,W,t)$, $V_W = V_W(H,W,t)$. Partially differentiating the Bellman equation (3.6) with respect to H and W, and using the first order optimality conditions (3.5.a-c) along with Itô's lemma, one could establish that under the additional assumption of $\eta_\phi = -H\frac{\phi'(H)}{\phi(H)}$ and $\eta_\varepsilon = -H\frac{\varepsilon'(H)}{\varepsilon(H)}$, $\eta_\phi = \eta_\varepsilon \overset{def}{=} \eta < 0$ - constant

elasticity of $\phi(\cdot)$, $\varepsilon(\cdot)$ with respect to H, the following dynamic stochastic equations for marginal value of health and wealth can be obtained (see Appendix for derivation):

$$dV_H = \{[\rho + \delta - \psi(m)]V_H + \frac{V_W \omega \varepsilon(H)\eta}{H} - V_{HH} H \sigma_H^2 - \\ - V_{HW} W \sigma_{HW}\} dt + V_{HH} H dh_t + V_{HW} W dw_t \quad \text{and} \tag{3.7}$$

$$dV_W = \{(\rho - r)V_W - V_{HW} H \sigma_{HW} - V_{WW} W \sigma_W^2\} dt + \\ + V_{WH} H dh_t + V_{WW} W dw_t \tag{3.8}$$

Note that in the model without uncertainty equation (3.8) reduces to the standard Euler's equation. Namely, assuming that $dw_t = dh_t = 0$, and $\sigma_W^2 = \sigma_H^2 = \sigma_{HW} = 0$, the first order condition (3.5.a) and the optimal evolution (3.8) imply that $dV_W = (\rho - r)V_W$, from which the familiar Euler's equation follows: $\frac{1}{U_C}\frac{dU_C}{dt} = \rho - r$.

In the extreme case of no uncertainty, the shadow price of wealth, or marginal impact of wealth on the value function, depends on the interest rate and a subjective discount rate only. The marginal value of health depends on a much larger set of model parameters. It is positively related to the subjective discount rate, the depreciation rate of health capital, and price of medical care. Increase in any of these leads to the higher marginal value of health, and hence lower optimal stock of health capital. To the contrary, Increases in the health investment rate, wage rate, efficiency parameter and the steepness of the health investment schedule lead to the higher optimal health capital stock.

Under uncertainty, a marginal value of health is higher, hence the equilibrium stock of health is lower. The positive correlation between wealth and health shocks has a negative effect on the expected marginal value of health (hence, a positive effect on the equilibrium level of health capital), and a negative effect on the expected marginal value of wealth (positive effect on the equilibrium stock of wealth). Higher variance of wealth leads to higher expected marginal value of wealth and is associated with the lower optimal level of wealth. Variance of

wealth (health) adjusted by the risk aversion parameter of the value function serves as an extra discount factor in the value of wealth (health) accumulation equation.

3.2. Elasticity with Respect to Coinsurance Rate

To study partial effects of changes in coinsurance rate k on equilibrium solution, partially differentiate equilibrium conditions (3.5.a-c) with respect to k, and treat H, W, V_H and V_W as functions of parameter k. This yields the following linear system in $z=(\frac{\partial c}{\partial k}, \frac{\partial \lambda}{\partial k}, \frac{\partial m}{\partial k})'$:

(3.9) $$Az=b,$$

where $A=\begin{bmatrix} U_{cc} & U_{c\lambda}\phi(H) & 0 \\ U_{\lambda c}\phi(H) & U_{\lambda\lambda}\phi^2(H) & 0 \\ 0 & 0 & V_H H\psi''(m) \end{bmatrix}$ and

$$b=\begin{bmatrix} \frac{\partial V_W}{\partial k} - U_{c\lambda}\phi'(H)\lambda\frac{\partial H}{\partial k} \\ \{\omega V_W \varepsilon'(H) - \phi(H)U_{\lambda\lambda}\phi'(H)\lambda - U_\lambda\phi'(H)\}\frac{\partial H}{\partial k} + \omega\varepsilon(H)\frac{\partial V_W}{\partial k} \\ k\chi\frac{\partial V_W}{\partial k} - \psi'(m)H\frac{\partial V_H}{\partial k} - \psi'(m)V_H\frac{\partial H}{\partial k} \end{bmatrix}.$$

Introducing elasticities with respect to k,

$$\eta_{V_W,k} = -\frac{k}{V_W}\frac{\partial V_W}{\partial k}, \quad \eta_{V_H,k} = -\frac{k}{V_H}\frac{\partial V_H}{\partial k}, \quad \eta_{W,k} = -\frac{k}{W}\frac{\partial W}{\partial k}, \eta_{H,k} = -\frac{k}{H}\frac{\partial H}{\partial k},$$

and using the assumption of constant relative risk aversion of the health investment function with respect to m, that is,

$$-\frac{m\psi''(m)}{\psi'(m)} = \eta_2 > 0,$$

the system (3.9) and the optimality condition (3.5.c) immediately yield

(3.10) $$\eta_{m,k} = \eta_{H,k} + \eta_{V_H,k} - \eta_2 \eta_{V_W,k},$$

where $\eta_{m,k} = -\frac{k}{m}\frac{\partial m}{\partial k}$ - elasticity of demand for medical care with respect to the coinsurance rate.

Solving for $\frac{\partial c}{\partial k}, \frac{\partial \lambda}{\partial k}$ and using the optimality conditions (3.5.a-b), the following relationships are derived under the assumption $\eta_\varepsilon = \eta_\phi = \eta$:

(3.11) $$\eta_{c,k} = \frac{1}{c}\frac{U_{\lambda\lambda}U_c - U_{c\lambda}U_\lambda}{U_{cc}U_{\lambda\lambda} - U^2_{c\lambda}}\eta_{V_W,k}, \text{ and}$$

(3.12) $$\eta_{\lambda,k} = \frac{\eta}{\lambda}\eta_{H,k} - \frac{1}{\lambda\phi(H)}\frac{U_{\lambda c}U_c - U_{cc}U_\lambda}{U_{cc}U_{\lambda\lambda} - U^2_{c\lambda}}\eta_{V_W,k},$$

where $\eta_{c,k} = -\frac{k}{c}\frac{\partial c}{\partial k}$, $\eta_{\lambda,k} = -\frac{k}{\lambda}\frac{\partial \lambda}{\partial k}$ - elasticities of consumption and leisure with respect to the coinsurance rate.

Expressions (3.10)-(3.12) can be further simplified by noting that

$$\eta_{V_W,k} = -\frac{k}{V_W}\frac{\partial V_W}{\partial k} = -\frac{k}{V_W}\frac{\partial V_W}{\partial W}\frac{\partial W}{\partial k} = -\frac{V_{WW}W}{V_W}\frac{k}{W}\frac{\partial W}{\partial k} = -R_{WW}\eta_{W,k},$$

and analogously $\eta_{V_H,k} = -R_{HH}\eta_{H,k}$, where $R_{WW}, R_{HH} \in R^+$ are the coefficients of relative risk aversion defined as $-\frac{HV_{HH}}{V_H} = R_{HH}$, $-\frac{WV_{WW}}{V_W} = R_{WW}$.

Hence,

(3.10') $$\eta_{m,k} = (1 - R_{HH})\eta_{H,k} + \eta_2 R_{WW}\eta_{W,k},$$

(3.11') $$\eta_{c,k} = -\frac{1}{c}\frac{U_{\lambda\lambda}U_c - U_{c\lambda}U_\lambda}{U_{cc}U_{\lambda\lambda} - U^2{}_{c\lambda}} R_{WW}\eta_{W,k},$$

(3.12') $$\eta_{\lambda,k} = \frac{\eta}{\lambda}\eta_{H,k} + \frac{1}{\lambda\phi(H)}\frac{U_{\lambda c}U_c - U_{cc}U_\lambda}{U_{cc}U_{\lambda\lambda} - U^2{}_{c\lambda}} R_{WW}\eta_{W,k}.$$

These are the equilibrium conditions for the *ex-post* optimal medical expenditure, consumption and leisure. Elasticity of demand for medical care with respect to the coinsurance rate depends on both the elasticity of health and wealth. Noting that $\eta_2 > 0$, $R_{WW}, R_{HH} > 0$, the change in demand for medical care resulting from the change in coinsurance rate is composed of two effects, health and income (wealth) effect, which might be pulling in opposite directions. There is a co-movement of demand for medical care with changes in wealth due to the increase in the coinsurance parameter. At the same time, direction of change in demand for medical care attributed to change in health status depends on the degree of risk aversion with respect to health. If $R_{HH} < 1$, then demand for medical care is decreasing when the coinsurance rate increases, assuming that the increase in coinsurance rate leads to both a lower health capital stock ($\eta_{H,k} > 0$) and lower wealth ($\eta_{W,k} > 0$). In case of a unit risk aversion to health, $R_{HH} = 1$, the change in demand for medical care is driven by the income effect only. If the consumer exhibits relative risk aversion to health of the degree greater than 1, then assuming no income effect from the change in coinsurance rate ($\eta_{W,k} = 0$), the direction of change in demand for medical care is in fact opposite to the direction of change in health status. In this case, the demand for medical care can increase with rise in coinsurance rate, to offset negative impact to health which was caused by increase in coinsurance rate.

Changes in demand for consumption good depend on the income effect only, and are inversely related to the current magnitude of consumption. The numerator of the ratio in (3.11'), $U_{\lambda\lambda}U_c - U_{c\lambda}U_\lambda$, is always negative under the regular assumptions on the utility function. The denominator, $U_{cc}U_{\lambda\lambda} - U^2{}_{c\lambda}$, is positive for the same reason (assuming strict concavity).

Hence, the direction of change in consumption is the same as change in wealth when the coinsurance rate changes.

Analyzing the demand for leisure, the first effect is linked to the changes in health stock. Health enters the utility function by means of the health-adjustment to leisure, represented by the function $\phi(H)$. The first term in (3.12') is negative ($\eta_{H,k}$ >0, η <0), driving the demand for leisure in the opposite direction to the change in health. If the stock of health is reduced due to the increase in coinsurance rate, then more leisure is needed to enjoy the same level of utility from the health-adjusted leisure. At the same time, there is an income effect of reduced labor supply. Note that the efficiency of labor also depends on health status through the efficiency function $\varepsilon(H)$, and it is assumed that both $\phi(H)$ and $\varepsilon(H)$ have the same elasticity with respect to health, η. Under this specification, the effect of reduction in health on leisure combines both the increase in desired leisure to keep the level of health-adjusted leisure constant, and the decrease in desired leisure to keep the efficiency of labor constant. The income effect is given by the second term, in which the numerator $U_{\lambda c}U_c - U_{cc}U_\lambda$ >0, and the denominator, $U_{cc}U_{\lambda\lambda} - U^2{}_{c\lambda}$ >0, are both positive. If the change in coinsurance rate leads to the increase in wealth, then the demand for leisure increases. The final effect on the demand for leisure depends on the relative strength of these effects. Percentage change in leisure due to the change in coinsurance parameter is inversely related to the current level of leisure. Those are the comparative-static implications of the optimality conditions (3.10')-(3.12'). The last two of these conditions can be also re-written as

$$\eta_{c,k} = U_\lambda^2 \frac{\frac{\partial}{\partial\lambda}(\frac{U_c}{U_\lambda})}{\Delta} R_{WW}\eta_{W,k}, \quad \eta_{\lambda,k} = \frac{\eta}{\lambda}\eta_{H,k} + \frac{1}{\lambda\phi(H)} U_c^2 \frac{\frac{\partial}{\partial c}(\frac{U_\lambda}{U_c})}{\Delta} R_{WW}\eta_{W,k},$$

where $\Delta = U_{cc}U_{\lambda\lambda} - U^2{}_{c\lambda}$ >0.

3.3. Optimal Coinsurance Rate

Returning to the beginning of the interval [*t, t+dt*), the consumer can select the value of the coinsurance parameter k which maximizes the expected utility, with the knowledge that after the shocks are realized, the optimal behavior is given by (3.5.a-c). The consumer maximizes

$$
\begin{aligned}
H = \quad & U(c,\phi(H)\lambda) + V_t - \rho V + V_H(\psi(m) - \delta)H + \\
& + V_W(rW + \omega\varepsilon(H)(1-\lambda) - c - \pi - k\chi m) + \\
& + \frac{1}{2}V_{HH}H^2\sigma_H^2 + V_{HW}HW\sigma_{HW} + \frac{1}{2}V_{WW}W^2\sigma_W^2
\end{aligned}
$$

with respect to k.

The Bellman equation (BE) has to be satisfied identically at the optimum k^* : $H(k^*)$=0.

Partially differentiating BE with respect to k yields

(3.13)

$$U_c \frac{\partial c}{\partial k} + U_\lambda \phi'(H)\frac{\partial H}{\partial k}\lambda + U_\lambda \phi(H)\frac{\partial \lambda}{\partial k} - \rho V_k + V_{kt} + V_{kH}(\psi(m)-\delta)H +$$
$$+ V_H \psi'(m)H\frac{\partial m}{\partial k} + V_H(\psi(m)-\delta)\frac{\partial H}{\partial k} + V_{kW}(rW + \omega\varepsilon(H)(1-\lambda) - \pi - c - \chi km) +$$
$$+ V_W(r\frac{\partial W}{\partial k} + \omega\varepsilon'(H)\frac{\partial H}{\partial k}(1-\lambda) - \omega\varepsilon(H)\frac{\partial \lambda}{\partial k} - \frac{\partial \pi}{\partial k} - \frac{\partial c}{\partial k} - \chi m - k\chi\frac{\partial m}{\partial k}) +$$
$$+ \frac{1}{2}V_{kHH}H^2\sigma_H^2 + V_{HH}H\sigma_H^2\frac{\partial H}{\partial k} + V_{kWH}HW\sigma_{HW} + V_{WH}W\sigma_{HW}\frac{\partial H}{\partial k} + V_{WH}H\sigma_{HW}\frac{\partial W}{\partial k} +$$
$$+ \frac{1}{2}V_{kWW}W^2\sigma_W^2 + V_{WW}W\sigma_W^2\frac{\partial W}{\partial k} = 0.$$

Using the first order optimality conditions (3.5.a-c) for the optimal *ex-post* choice of c_t, λ_t, m_t, and applying the Itô's Lemma

$$dV_k = V_{kt}dt + V_{kH}dH + V_{kW}dW + (\frac{1}{2}V_{kHH}H^2\sigma_H^2 + V_{kHW}HW\sigma_{HW} + \frac{1}{2}V_{kWW}W^2\sigma_W^2)dt,$$

the following evolution of V_k is derived:

(3.14)

$$dV_k = [\rho V_k - U_\lambda \phi'(H)\lambda\frac{\partial H}{\partial k} - V_H(\psi(m)-\delta)\frac{\partial H}{\partial k} - V_W(r\frac{\partial W}{\partial k} + \omega\varepsilon'(H)\frac{\partial H}{\partial k}(1-\lambda) - \frac{\partial \pi}{\partial k} - \chi m) -$$
$$- V_{WH}H\sigma_{HW}\frac{\partial W}{\partial k} - V_{WW}W\sigma_W^2\frac{\partial W}{\partial k} - V_{HH}H\sigma_H^2\frac{\partial H}{\partial k} - V_{WH}W\sigma_{HW}\frac{\partial H}{\partial k}]dt +$$
$$+ V_{Hk}Hdh_t + V_{Wk}Wdw_t$$

Substituting $V_k = V_H\frac{\partial H}{\partial k} + V_W\frac{\partial W}{\partial k}$ and $dV_k = dV_H\frac{\partial H}{\partial k} + V_H d(\frac{\partial H}{\partial k}) + dV_W\frac{\partial W}{\partial k} + V_W d(\frac{\partial W}{\partial k})$

into (3.14), and using the optimal evolution of V_H, V_W for the *ex-post* problem given by

$$dV_H = \{[\rho + \delta - \psi(m)]V_H + \frac{V_W\omega\varepsilon(H)\eta}{H} - V_{HH}H\sigma_H^2 - V_{HW}W\sigma_{HW}\}dt + \quad \text{and}$$
$$+ V_{HH}Hdh_t + V_{HW}Wdw_t$$

$$dV_W = \{(\rho - r)V_W - V_{HW}H\sigma_{HW} - V_{WW}W\sigma_W^2\}dt +$$
$$+ V_{WH}Hdh_t + V_{WW}Wdw_t$$

it is not difficult to show that

$$V_H d(\frac{\partial H}{\partial k}) + V_W d(\frac{\partial W}{\partial k}) = V_W \left[\frac{\partial \pi}{\partial k} + \chi m\right] dt . \tag{3.15}$$

The last expression has to be satisfied identically at the optimum coinsurance rate chosen by a consumer.

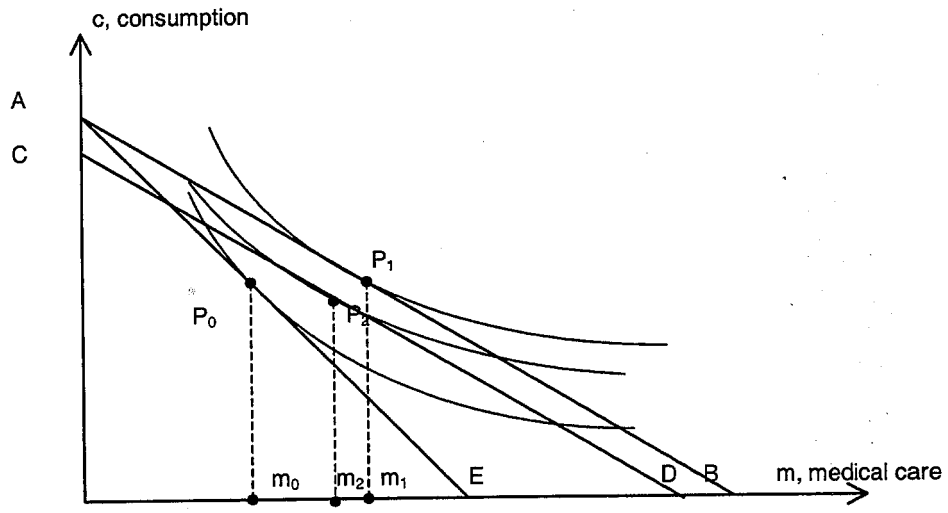
Equation (3.15) states that the sum of utility-weighted gains from the change in H_k, W_k is equal at optimum to the rate of change in wealth due to the increase in coinsurance parameter. There are two counteracting effects. First, an increase in coinsurance leads to higher out-of-pocket medical expenditure given by the term χm. Second, there is a reduction in premium due to the increase of coinsurance rate, $\frac{\partial \pi}{\partial k} < 0$. Total effect depends on a relative strength of these two components.

Implications of the theoretical model can be compared to the results of Phelps [1973]. Figure I represents the effects of coinsurance rate on the demand for medical care in the Phelps's model[3]. AE represents an uninsured budget line, and P_0 is the original equilibrium. When the coinsurance is introduced, the out-of-pocket price of medical care in terms of the consumption good decreases, which leads to the rotation of budget line to AB, if the income effect through premium is not taken into account. The new position is P_1, with the amount of medical care demanded $m_1 > m_0$. In reality, the rotated budget line must shift to CD to reflect amount of premium charged for the insurance contract, yielding the equilibrium point P_2, and medical care $m_2 > m_0$. The final amount of medical care consumed with introduction of insurance on average exceeds the quantity consumed when no insurance is present ($\frac{\partial m}{\partial k} < 0$). By adjusting a premium loading, it is possible to constrain budget so that demand for medical care

[3] Phelps (1973), pg. 31, Fig. 6.

will be rising with the coinsurance rate. This is also possible in our model, through combination of (3.10') and (3.15).

Figure 1. Average Effects Of Coinsurance On Demand For Medical Care



4. CONCLUSION

This paper contributes to the research into demand for health and medical care under uncertainty by constructing a continuous time stochastic model in which both health and wealth are governed by possibly correlated Wiener processes. The model includes an endogenous leisure (labor supply) decision and incorporates health insurance implemented as a two-stage procedure. The optimal coinsurance rate is chosen *ex-ante* according to the equilibrium condition, and the optimal medical care, consumption and leisure are derived *ex-post.*

This paper establishes a theoretical relationship between the coinsurance rate elasticity of the demand for medical care and the coinsurance elasticities of health and wealth. If an increase in coinsurance rate leads to the lower level of health, and the income effect is eliminated by an appropriate adjustment to the insurance premium, then the demand for medical care can either increase or decrease, depending on the degree of the relative risk aversion with respect to health. It has been found that for the unit risk aversion to health, changes in demand for medical care are purely income-driven. If the risk aversion with respect to health is less (greater) than one, then a decrease in health level due to the increase in coinsurance parameter will lead to a lower (higher) level of demand for medical care.

Coinsurance rate elasticities of consumption and leisure have also been obtained. It is shown that changes in consumption due to the increase in coinsurance rate are driven by the income effect, and that the overall effect of change in the coinsurance rate on leisure (and labor supply) is ambiguous. These predictions depend on a range of assumptions about the underlying utility function (namely, constant relative risk aversion with respect to health and wealth), and on the assumption of constant and equal elasticity of the health-adjustment factor in the utility function, and the transformation function in the health accumulation equation. Without making these assumptions, analytical tractability of the optimization problem would be significantly impaired. Further research is needed into relaxing the assumptions of the model and its expansion to endogenize lifespan by incorporating a positive threshold - a critical level of health, below which death occurs.

This paper contributes to the existing literature by proposing a new dynamic model of the demand for medical care with insurance against medical expenditure, which incorporates labor supply and recognizes the random nature of health and shocks to income. Some assumptions of and implications from the model will be tested empirically in the future work.

APPENDIX. DERIVATION OF EVOLUTION OF MARGINAL VALUE OF HEALTH AND WEALTH

Partially differentiating the Bellman equation (3.6) with respect to H, and using the first order optimality conditions (3.5.a-c), one could establish that

$$\begin{aligned}(\psi(m)-\rho-\delta)V_H + U_\lambda\phi'(H)\lambda + V_{Ht} + V_{HH}(\psi(m)-\delta)H + \\ +V_{WH}(rW+(1-\lambda)\omega\varepsilon(H)-c-\pi-k\chi m)+V_W\omega\varepsilon'(H)(1-\lambda)+ \\ +\frac{1}{2}V_{HHH}H^2\sigma_H^2 + V_{HHW}HW\sigma_{HW} + \frac{1}{2}V_{HWW}W^2\sigma_W^2 + \\ +V_{HH}H\sigma_H^2 + V_{HW}W\sigma_{HW} = 0\end{aligned} \tag{A.1}$$

This could be further simplified by noting that

$U_\lambda\phi'(H)\lambda = \dfrac{V_W\omega\varepsilon(H)\phi'(H)}{\phi(H)}\lambda$, and collecting terms containing V_W in (A.1) yields the following expression:

$$\begin{aligned}(\psi(m)-\rho-\delta)V_H + V_{Ht} + V_{HH}(\psi(m)-\delta)H + \\ +V_{HW}(rW+(1-\lambda)\omega\varepsilon(H)-c-\chi m)+ \\ +V_W\omega\varepsilon(H)\left(\frac{\phi'(H)}{\phi(H)}\lambda + \frac{\varepsilon'(H)}{\varepsilon(H)}(1-\lambda)\right)+ \\ +\frac{1}{2}V_{HHH}H^2\sigma_H^2 + V_{HHW}HW\sigma_{HW} + \\ +\frac{1}{2}V_{HWW}W^2\sigma_W^2 + V_{HH}H\sigma_H^2 + V_{HW}W\sigma_{HW} = 0\end{aligned} \tag{A.2}$$

Finally, by noting that $\dfrac{V_W}{H} = \dfrac{V_H\psi'(m)}{k\chi}$, and by denoting $\eta_\phi = -H\dfrac{\phi'(H)}{\phi(H)}$ and $\eta_\varepsilon = -H\dfrac{\varepsilon'(H)}{\varepsilon(H)}$, $\eta_\phi, \eta_\varepsilon < 0$, equation (5.A.2) is reduced to the following:

$$\left[\psi(m)-\rho-\delta-\frac{\omega\varepsilon(H)\psi'(m)}{k\chi}\left(\eta_\phi\lambda+\eta_\varepsilon(1-\lambda)\right)\right]V_H+V_{Ht}+$$

$$+V_{HH}(h(m)-\delta)H+$$

(A.3) $$+V_{WW}(rW+(1-\lambda)\omega\varepsilon(H)-c-\chi m)+$$

$$+\frac{1}{2}V_{HHH}H^2\sigma_H^2+V_{HHW}HW\sigma_{HW}+\frac{1}{2}V_{HWW}W^2\sigma_W^2+$$

$$+V_{HH}H\sigma_H^2+V_{HW}W\sigma_{HW}=0$$

Using Itô's lemma,

$$dV_H=V_{Ht}dt+V_{HH}dH+V_{HW}dW+(\frac{1}{2}V_{HHH}H^2\sigma_H^2+V_{HHW}HW\sigma_{HW}+\frac{1}{2}V_{HWW}W^2\sigma_W^2)dt,$$

and substituting from (A.3), it follows that

(A.4) $$dV_H=\{\left[\rho+\delta-\psi(m)+\frac{\omega\varepsilon(H)\psi'(m)}{k\chi}\left(\eta_\phi\lambda+\eta_\varepsilon(1-\lambda)\right)\right]V_H-V_{HH}H\sigma_H^2-$$

$$-V_{HW}W\sigma_{HW}\}dt+V_{HH}Hdh_t+V_{HW}Wdw_t$$

Suppose $\eta_\phi=\eta_\varepsilon\overset{def}{=}\eta<0$ - constant and equal elasticity of $\phi(\cdot)$, $\varepsilon(\cdot)$ with respect to *H*. Then expression (A.4) could be further simplified to the following form,

(A.5) $$dV_H=\{\left[\rho+\delta-\psi(m)(1-\frac{\omega\varepsilon(H)\psi'(m)\eta}{k\chi\psi(m)}\right]V_H-V_{HH}H\sigma_H^2-V_{HW}W\sigma_{HW}\}dt+$$

$$+V_{HH}Hdh_t+V_{HW}Wdw_t$$

Using optimality condition (3.5.b), and equation (3.7) in the text is obtained.

The procedure for the other state variable, wealth, is completely analogous. Partially differentiating the Bellman equation (3.6) with respect to *W*, and using the first order optimality conditions (3.5.a-c) and the Itô's lemma for dV_W, one could establish that

(A.6) $$dV_W=\{(\rho-r)V_W-V_{HW}H\sigma_{HW}-V_{WW}W\sigma_W^2\}dt+$$

$$+V_{WH}Hdh_t+V_{WW}Wdw_t$$

which corresponds to (3.8) in the text.

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