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On adaptation, life-extension possibilities and the demand for health[1]

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Abstract

The purpose of this paper is to analyse the impacts of adaptation to a falling health state on the demand for health and medical care. This is done by integrating adaptation processes in the pure consumption model of Grossman.
We also modify the model in another direction by introducing an uncertain lifetime. Model simulations show that adaptation affects the health variables by lowering the incentives to invest in health, as well as smoothening the optimal health stock path over the life cycle. Whether or not the risk of mortality is an object of choice has important effects on the joint development of the health variables.

***JEL classification*:** C61; D91; I12.

Keywords: Grossman model; Demand for health; Adaptation; Life extension; Ageing.

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1. INTRODUCTION

In standard neoclassical economics, the main carriers of utility or well-being are the absolute characteristics (or levels) of goods. However, some economic modelling deviates from this approach by introducing *reference points* in objective functions. This literature can be classified into two distinct groups. The first and most important approach is "status models" for which certain levels of variables of other individuals or groups constitute the reference points for the object of the study (*external reference points*). Analyses of this kind are found in Hirsch (1976), Frank (1985; 1989) and Ng and Wang (1993) as well as in the works of Veblen (1899), Duesenberry (1949) and Johansen (1961). The above studies focus on individual satisfaction being determined by relative standings in consumption and income, and introduce concepts like "conspicuous consumption", "positional goods" or "demonstrative consumption".[2]

A second group of models applies *internal reference points* for the individual being considered. Studies of this kind include works on habits and addiction for which (utility of) present consumption depends on the history of past consumption (see, e.g., Pollak, 1970; 1976, and Becker and Murphy, 1986), as well as aspiration models. Here, utility generated by a consumption bundle depends on the individual's aspiration level represented by own expectations about future performance. Aspiration levels are often perceived as being endogenous, depending on factors such as past or current performance relative to actual performance (see Ng and Wang, 1993, for references).

Yet another type of internal reference points is *adaptation theory*. The concept of adaptation originates from biology where it is used to describe adjustments to the conditions under which species must live in order to survive.[3] Adaptation processes are also discussed in economic literature on preference formation (see Ng and Wang 1993; Rabin, 1998; Frank, 1989) as well as in studies on health status evaluation where they are used to describe the ability individuals have to cope or adapt to malign changes in health.[4] The theory postulates that humans are sensitive to context, frame,

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[2] See also Easterlin (1996) and Hellevik (1999) for survey evidence on this topic.

[3] See also work in psychology, e.g., Helson (1964).

[4] Adaptation is also related to changes in tastes, for instance tastes that are formed under conditions of truncated opportunity. Examples may be "the battered slave, the tamed housewife, the broken

or the current situation rather than absolute characteristics, only. In this perspective, adaptation suggests mechanisms different from those applied in traditional approaches on health demand such as the pioneering works of Grossman (1972a,b) and subsequent extensions (see, e.g., Muurinen, 1982; Wagstaff, 1986; Ehrlich and Chuma, 1990; Ried, 1998; Eisenring, 1999; Jacobson, 2000). Consequently, it would be of interest to investigate whether adaptation processes have implications for the results arrived in Grossman types of models, especially since some of their implications are contradicted by available evidence.[5]

In the Grossman model, health is considered a capital stock that increases due to investment (buying health services, medical goods, or spending time on healthy activities), and decreases in response to an advancing age. According to this model, there are three reasons why individuals demand health. First, health is a *consumption commodity* in the way that it directly enters the individual utility function. Good health implies higher utility than bad health for a given consumption level. The second reason to demand health is based on health as an *investment commodity*. Health determines the total amount of time available for market and non-market activities, e.g., bad health gives more sick days than good health. Available time increases in health, which again represents a monetary value. This may be thought of as a return to investment in health. The third reason follows from health determining the *length of life*. A good health condition may give a longer lifetime. Of the three reasons to demand health, adaptation will be important only for health as consumption good, i.e., how much the utility will be affected from changes in the objective health state.

We do not know any other studies that formalise adaptation processes.[6] In this paper, therefore, an effort is made to integrate adaptation to ageing in a formal model framework. This means that instead of studying rapid changes in health due sickness or accidents, we concentrate on the natural decline in health, as one grows older, i.e.,

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unemployed, the hopeless destitute" (see Sen, 1987, p.11). Thus, these processes are not always wanted.

5 Zweifel and Breyer, 1997, provide an overview of some studies. The results are rather mixed.

6 Kverndokk (2000) proposes several ways to extend the standard model for demand for health and medical care. Formal specifications of psychological aspects such as status seeking, identity seeking and health adaptation are suggested.

how we adapt to becoming old.[7] In order to keep the analysis tractable we restrict ourselves to the pure consumption model of Grossman (1972a,b).[8] The model is extended in yet another direction, by leaving the common assumption of a fixed lifetime or an endogenous lifetime being determined by the stock of health capital reaching a minimum level (see, e.g., Wolfe, 1985, Ehrlich and Chuma, 1990, Ried, 1998, Eisenring, 1999 and Jacobson, 2000). Rather we prefer to introduce uncertainty into the model by modelling a probability of life-termination decreasing in the stock of health capital (i.e., the random date of death is conditioned upon objective health status). This allows us to split the demand for health in two parts, as a consumption commodity and as a mean to extend life. Only the first part is affected by adaptation.

In the next section we define the concept of adaptation and discusses its relationship with ageing. In section 3 the theoretical model is presented. Section 4 describes the main results from numerical simulations of the model. In particular, we focus on the implications of the adaptation process for health demand including shifts in exogenous variables and model parameters. Section 5 concludes.

2. ADAPTATION AND AGEING

In the literature, adaptation processes are mainly discussed i) in the context of abrupt and unexpected changes in health conditions and ii) for individuals with handicaps and chronic illnesses. However, adaptation may also be relevant in the context of a gradually declining health due to an advancing age. The fact that health deteriorates with age is common knowledge and most likely people realise that their future evaluations of health will be conditioned on age itself. In this perspective it seems adequate to integrate adaptation in a health planning perspective.

[7] In the Grossman model, utility is increasing in consumption and health, where consumption is viewed as an aggregate of all commodities besides health that enter the utility function including leisure time. Thus, if the health stock falls over time due to ageing, the way to maintain the utility level is to increase material consumption or leisure time. While leisure time increases when people retire, data for the UK and the US suggest that both consumption and income has a hump-shaped profile, with a peak around age 45 (see Attanasio and Banks, 1998). The effect on utility may, therefore, be ambiguous. However one indication is found in a Norwegian survey on self-reported happiness (Hellevik, 1999), where good health is found to be one of the main determinants. The study reports a falling level of happiness with age, from a top at around age 25-35. According to the study, reasons for lower level of happiness among elderly people may be a lower health state as well as loneliness. Adaptation will reduce the effect of the first element.

According to Heyink (1993, p. 1332), adaptation may be defined as “an intrapsychic process in which past, present, and future situations are circumstances given such cognitive and emotional meaning that an acceptable level of well-being is achieved”. Mentzel et al., (1999) perceive adaptation as the alteration of activities, desires, goals, and values in response to changes in health states and suggest six different factors all considered to be potential elements of adaptation. These are; skill enhancement, activity adjustment, substantive goal adjustment, lowered expectations, heightened stoicism and altered conception of health. The same study distinguishes adaptation processes both from initial shocks related to health state changes and the increased knowledge that arises from experiencing adverse health conditions.

There is some empirical evidence supporting adaptation processes when health deteriorates naturally over time.[9] In health surveys for Norway conducted by Statistics Norway, see SSB (1999), elderly people in general consider their health as good, even if many of them reported serious or less serious illnesses or worries. For people above age 80, 20 per cent reported bad health. This is a bit surprising as 27 per cent of the respondents above age 80 reported that they had an illness that strongly affected their everyday life. SSB suggests that the reason may be that health expectations are reduced when one live as long as 80 years or more. Cassilleth et al., (1984) found, in a study examining 758 patients, that older people seem to develop more effective skills with which to manage stressful life events. ”There may be a biological, evolutionary advantage for older patients, enabling them to adapt to illnesses that are epidemiologically associated with advancing years” (p. 509). Van Maanen (1988) reports studies among self-defined healthy American born elderly and ill-healthy British born older persons. The results indicate that many dimensions other than the absence of disease and illnesses determine the perception of health. The older the person, the more emphasis was placed on health as a state of mind, even in situations of a gradually falling body. Groot (2000) found elderly people to report better health

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[8] Analysing adaptation in relation to health as an investment good seems less relevant since income tends to be a function of objective health rather than subjective health evaluations.

[9] Empirically, it may be difficult to distinguish between adaptation and comparisons to reference groups, as both effects may give the same result (see Groot, 2000). With external reference points, elderly people compare themselves to other, e.g., people of their own age, while with internal reference

than younger people. One reason may be that elderly people may be more adaptive than younger people: "Older people may have become more accustomed and have had more time to adapt to their health impairments" (p. 413).

Findings from studies on adaptation have also triggered a debate on whom to ask about the utility of health states (patients, health personnel, or the general public) and whether patients, if asked, should report ex-ante or ex-post utilities.[10] E.g., Adang (1997) found that that people who have been through successful transplants assess their pre-transplant quality of life lower relative to assessments made before the transplants took place. Also, Sackett and Torrance (1978) found that patients rated the value of an impaired state of health more highly than the general public, suggesting that people with deteriorating health adapt to their health condition over time.

This evidence suggests that people may adapt to a lower health level over time. One implication is that even if one believes that the adaptive behaviour should not be taken into account in health policies such as allocating scarce resources, adaptation may be important in explaining behaviour, such as the demand for medical care. We, therefore, include an adaptive health measure in a theoretical and numerical analysis explaining individual behaviour.

3. THE MODEL

In this section we present a theoretical model, which is based on the pure consumption model of Grossman but modified in two respects. First, adaptation processes are introduced, and second, we apply a probabilistic approach to life termination (uncertain lifetime).

3.1 The adaptation process

The utility of an individual at any point of time, t, is represented by the following function:

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points, they compare with themselves, e.g., their own health in earlier periods of time. The latter means that they may adapt to a certain health state.

[10] Cost-utility and cost-effectiveness analysis are methods designed to help decision-makers in the health sector to distribute scarce resources to where they yield the greatest benefits. Such methods

(1) $U_t = U(C_t, K_t)$

C denotes consumption of goods and K is a health-related variable for which utility assessments are being made (subjective health). The utility function is strictly concave in C and K.[10] The specification of the adaptive processes is inspired by Hoel and Isaksen (1994);[11]

$$(2)\quad K_t = \frac{H_0}{1+\beta} + (1+\beta)\int_0^t e^{-\beta(t-\tau)} \dot{H}_\tau d\tau, \qquad \beta \geq 0$$

where H denotes the objective health state. From (2) it follows that subjective health, K, at date t becomes a function of the initial health endowment, $H_0 > 0$, and a weighted sum of all past changes in (objective) health states, $\dot{H}$. Thus, a dot over a variable represents its derivative with respect to time. The non-negative parameter β determines the "weight", and represents the degree of adaptation for which the rate rather than the state of health becomes important for well-being. The development in K over time follows the differential equation in (3):

$$(3)\quad \dot{K}_t = \frac{\beta}{1+\beta} H_0 - \beta K_t + (1+\beta)\dot{H}_t$$

Considering two special cases, $\beta \to \infty$ and β = 0. From (2) we find:

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require an estimate of health states. One methodology for estimating societal value of healthy interventions suggests the use of individual utilities.

[10] Our model can be considered a variant of the theory of tastes as presented in Becker (1996). Equation (1) represents an extended utility function, which is a stable function over time of the goods consumed and also of the health related capital stock. If an unexpected event that reduces the future objective health stock happens, the utility function will not change but there will be a change in the utility level. However, the subutility function that depends only on goods is unstable, as it will shift dependent on the level of the health related capital stock. In this case, the preferences for goods become endogenous, determined by the individual's health history, so that the individual rank consumption goods differently after experienced a change in health.

[11] Hoel and Isaksen (1994) apply a related specification when introducing global temperature changes rather than temperature level as the argument in a global warming damage function.

(4) $K_t = H_0 + \int_0^t \dot{H}_\tau d\tau = H_t, \quad for \quad \beta = 0$

(5) $\lim_{\beta \to \infty} K_t = \dot{H}_t$

Thus, if $\beta = 0$, there is no adaptation. Subjective health coincides with objective health and the utility function in (1) becomes equal to those applied in human capital models in the health literature. For $\beta \to \infty$, however, subjective health equals the current change in the objective health state only. This can be denoted "perfect adaptation" since the individual is indifferent to absolute levels of objective health but responds only to the most recent change in the health state. He suffers a loss only in the period when the health is deteriorated, and will adapt perfectly to this change from the next period onwards. For all other cases, i.e., $0 < \beta < \infty$, past changes in health states count less than current changes. If, e.g., $\beta = 0.05$, a current change in health is $e^{20\beta} = e = 2.71828$ times as important as a similar change in health 20 years ago.

Figure 1 illustrates the adaptation processes for the three cases above, with an abrupt change in health. Assume that the consumption level is constant and also that health state is constant at $H_t = H_1$ for an interval of time, $t < t_1$. Thus, in this time period, utility is constant for all possible values of β.[13] At t_1 a sudden negative change in health occurs, and the health state will remain at a lower level, $H_t = H_2 < H_1$, for $t \geq t_1$. This reduction in H will cause an immediate downward shift in both K and utility, however the development in these variables depends on the value of β. For $\beta = 0$, K = H and utility will remain constant at a lower level, see panel a). If $\beta \to \infty$, the individual will suffer a loss only at time t_1 as shown in panel b). Finally, for $0 < \beta < \infty$, the individual will suffer an initial loss at $t = t_1$, but for later periods, K will steadily increase over time and approach its initial value. Utility will, therefore, also approach its previous level. Thus, this particular shift in health state becomes less decisive for the evaluations of health, the longer the distance in time, see panel c).

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[13] Note that the initial utility and also the drop in the utility will be different for the three different cases as K differs with β.

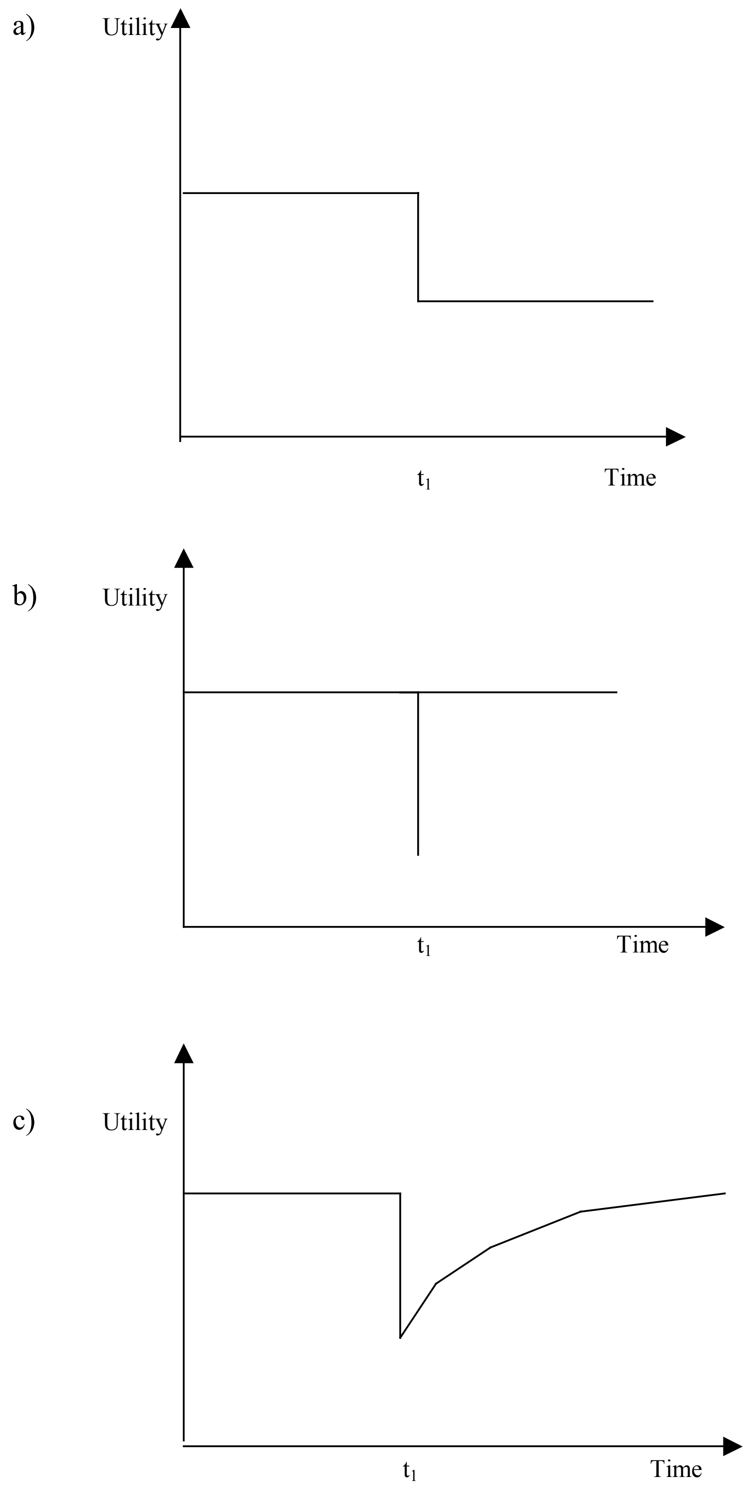

FIGURE 1: Adaptation processes for different values of β.
a) $\beta = 0$, b) $\beta \rightarrow \infty$, c) $0 < \beta < \infty$.

Our formulation in (2) seem to capture one essential feature of health adaptation processes being discussed in the literature, namely that a given level of health does not produce the same level of utility irrespective of the context in which it occurs. Changes in health states become decisive for health evaluations, introducing a sequence of internal reference points.

3.2 The uncertain lifetime

The lifetime of the individual is not known in the model. Rather, we assume that good health reduces the possibility of an early life termination, i.e., the higher the objective health state is, the lower is the probability of death defined by a utility equal to zero in all future periods. This introduces stochastic in the model. The individual is not able to determine the length of life, but can attach subjective probabilities to the occurrence of death, which are not revised over time. The probabilities depend on the objective health states. Thus, even if the individual is able to adapt to reduced health over time, he is aware of the objective health situation: An old person who has adapted to the health effects of ageing, knows that his objective health is not as good as it used to be, and, therefore, that the probability of dying is higher than before. As a consequence, the probabilities of dying are endogenous. For similar approaches to a random lifetime, see Cropper (1977) and Ehrlich (2000).

The individual's beliefs about a catastrophic event such as death at an arbitrarily instant of time is represented by a hazard function, which is the change in the probability of death to occur in the time interval (t, t+ε) given that death has not occurred at earlier instants of time (see, e.g., Kiefer, 1988, and Gjerde et al., 1999, for an application to climate catastrophes). The hazard function, $\dot{y}$, is related to the objective health state in the following way;

(6) $\dot{y}_t = h(H_t)$

where a higher health state means that the beliefs about the occurrence of a catastrophe, will undergo a negative shift. We assume that h' < 0 and h'' > 0, i.e., a given reduction in health has little impact on the probability of dying when the health stock is high, but has a high impact when the health stock is low. Furthermore, a hazard function is related to a survivor function, S, as follows;

$$(7)\ S_t = e^{-\int_0^t \dot{y}_s ds} = e^{-y_t}$$

The survivor function evaluated at time t is dependent on all hazard functions from the initial planning date and until t, and can be defined as the probability of experiencing no catastrophe by date t seen from the initial date.

Using (7), we can express the discounted expected lifetime utility of the individual, LU, where ρ is the time preference rate, and the utility at death is zero:[14]

$$(8)\ LU \equiv \int_0^\infty e^{-(\rho t + y_t)} U(C_t, K_t) dt$$

3.3 Investments in health

Due to the benefits of a high health state, the individual has an incentive to increase the stock of health by buying medical care,[15] $I \geq 0$. However, the health stock will depreciate due to ageing, with the depreciation rate set equal to δ_t, and $\dot{\delta}_t = \partial \delta_t / \partial t > 0$ for all t. This is a necessary condition for H to be a falling function of time at least after a certain age, see, Grossman (1972) and Ehrlich and Chuma (1990).

$$(9)\ \dot{H}_t = F(I_t) - \delta_t H_t$$

The F-function, which represents health investments, is concave in I, reflecting that there are diminishing returns from buying medical care at a given point of time.

[14] LU represents the discounted expected utility over an infinite period of time. However, as the risk of dying is increasing with lower health, the possibility of living over an infinite period of time can be ignored. Alternatively, the planning horizon can be set equal to D, where D is the maximum possible life length, see also the discussion in Ehrlich (2000).

[15] In the following, medical care is used as a proxy for all services and goods that can be bought to improve health.

3.4 The budget constraint

The individual's budget constraint is given by the following equation;

$$(10)\quad \dot{A}_t = rA_t + Y_t - q_t I_t - p_t C_t$$

where A is wealth, r is the market interest rate, Y is income, and q and p are prices of medical care and consumption respectively. Thus, in this model, income is independent of health. We restrict the wealth to be non-negative in all periods, i.e., $A_t \geq 0$.[16]

3.5 Solving the model

The forward-looking individual determines C and I in all periods by maximising expected lifetime utility, given by (8), subject to the development in the state variables K, y, H and A (see (3), (6), (9) and (10)), and the restrictions on H_0 and A_t. The introduction of the hazard function has enabled us to solve the stochastic maximisation problem by using deterministic control, and the current value Hamiltonian function, V, for this problem is;

$$(11)\quad \begin{aligned} V_t &= U(C_t, K_t)e^{-y_t} + \lambda_t(F(I_t) - \delta_t H_t) + \gamma_t(h(H_t)) \\ &+ \mu_t(rA_t + Y_t - q_t I_t - p_t C_t) + \eta_t(\frac{\beta}{1+\beta} H_0 - \beta K_t + (1+\beta)[F(I_t) - \delta_t H_t]) \end{aligned}$$

where λ, γ, μ, and η are current value shadow prices for objective health, death, money and subjective health, respectively. Since the Hamiltonian is strictly concave in C and I, the sufficient conditions assuming interior optimal solutions become (Seierstad and Sydsæter, 1987);

[16] A similar restriction is used in Ehrlich (2000). In deterministic models such as in Ehrlich and Chuma (1990), $A(T) \geq 0$, where T is the finite terminal period, is used. This allows for negative wealth in certain periods. However, as the time of death is stochastic, $A_t \geq 0$ is introduced to avoid that the person dies with a negative wealth.

(12) $\frac{\partial V_t}{\partial C_t} = U'_C(C_t, K_t)e^{-y_t} - \mu_t p_t = 0$

(13) $\frac{\partial V_t}{\partial I_t} = \lambda_t F'_I(I_t) - \mu_t q_t + \eta_t(1+\beta)F'_I(I_t) = 0$

(14) $\dot{\lambda}_t - \rho\lambda_t = -\frac{\partial V_t}{\partial H_t} = \eta_t(1+\beta)\delta_t + \lambda_t\delta_t - \gamma_t h'_H(H_t)$

(15) $\dot{\gamma}_t - \rho\gamma_t = -\frac{\partial V_t}{\partial y_t} = U(C_t, K_t)e^{-y_t}$

(16) $\dot{\mu}_t - \rho\mu_t = -\frac{\partial V_t}{\partial A_t} = -\mu_t r$

(17) $\dot{\eta}_t - \rho\eta_t = -\frac{\partial V_t}{\partial K_t} = -U'_K(C_t, K_t)e^{-y_t} + \beta\eta_t$

with the following transversality conditions:

(18) $\lim_{t\to\infty} e^{-\rho t}\lambda_t H_t = 0$; $\lim_{t\to\infty} e^{-\rho t}\gamma_t y_t = 0$; $\lim_{t\to\infty} e^{-\rho t}\mu_t A_t = 0$;
$\lim_{t\to\infty} e^{-\rho t}\eta_t K_t = 0$

The *flow conditions* for optimal consumption and optimal medical care use presented in (12) and (13) can be rewritten as follows;

(19) $p_t = \frac{U'_C(C_t, K_t)}{\mu_t} e^{-yt}$

(20) $q_t = \frac{F_I'(I_t)}{\mu_t}[\lambda_t + \eta_t(1+\beta)]$

where

(21) $\mu_t = \mu_0 e^{-(r-\rho)t}$

(22) $\gamma_t = -E\left\{\int_t^\tau U(C_v, K_v)e^{-(v-t)\rho}dv\right\}$

(23) $\eta_t = E\left\{ \int_t^{\tau} U'_K(C_v, K_v) e^{-(\rho+\beta)(v-t)} dv \right\}$

(24) $\lambda_t = \int_t^{\infty} e^{-[\rho(v-t)+\int_t^v \delta(s)ds]} \left[\gamma_v h'_H(H_v) - \eta_v (1+\beta)\delta_v \right] dv$

The expectation operator, E, in (22) and (23) is taken with respect to the random variable τ being the time of death.

From (19) it follows that along the *optimal consumption path* the price of the consumption good is equal to the money equivalent of the expected marginal utility of consumption. The expression for the *optimal path of medical care* in (20) is somewhat more complex. Here, the unit price of medical care is to equal the money equivalent of the expected net gains arising from buying an additional unit of medical care. It follows that net gains are determined by the shadow price of objective health, λ_t, and the shadow price of subjective health, η_t.

From (21), we see that $\mu_t > 0$, for $t < \infty$, i.e., the *shadow price of money* is positive and represents the additional utility benefit of an increase in A. It is decreasing over time for $r > \rho$. The *shadow price of a death*, γ, is the discounted expected utility measured in negative value, i.e., it represents the loss to the individual if he dies in period t. Thus, $\gamma_t < 0$, for $t < \infty$, see (22). We see from (23) that the *shadow price of the subjective health stock*, η, represents the discounted expected utility of an increase in K. As utility is increasing in K, $\eta_t > 0$ for $t < \infty$. The *shadow price of the objective health stock*, which is the expected utility effects of a current increase in H, discounted by the time preference rate as well as the depreciation rate, is determined by several effects, see (24). The first term within the parentheses represents the positive value an increase in H has on life extension. Further, a higher health stock has an impact on the subjective stock of health, which again has implications for utility. However, it will also involve costs in terms of additional future health depreciation (see 9). The two last effects are given by the second term within the parenthesis, which shows to be negative. Thus, λ_t can be positive or negative.

Define the shadow price of health measured in monetary units as

$$(25)\quad g_t \equiv \frac{\lambda_t}{\mu_t}$$

where *g* is the unit value of health capital. Using equations (14) and (16), we can derive the *stock condition* for the optimal level of health stock (see also Erlich and Chuma, 1990):

$$(26)\quad g_t(r + \delta_t - \frac{\dot{g}_t}{g_t}) = \frac{1}{\mu_t}\left[\gamma_t h'(H_t) - \eta_t(1+\beta)\delta_t\right]$$

The left-hand side of equation (26) is the instantaneous user cost of health capital, which has a similar form as the user cost of capital from investment theory. Thus, the user cost should equal the instantaneous marginal benefit of increasing the health stock with one unit. The latter term is the expected utility effects of an increase in the health stock, and consists of the same three effects as the shadow price of objective health, see above. The left hand side is also called the "marginal efficiency of capital" (MEC), see, e.g., Grossman (1972a).

As an illustration of the effects of adaptation, consider the stock conditions for the special cases, $\beta = 0$ and $\beta = \infty$. For $\beta = 0$, K = H, and there is no adaptation. Equation (26) then reduces to:

$$(27)\quad g_t(r + \delta_t - \frac{\dot{g}_t}{g_t}) = \frac{1}{\mu_t}\left[\gamma_t h'(H_t) + U'_H(C_t, H_t)e^{-y_t}\right]$$

For this case MEC is always positive, as an increase in health extends expected lifetime as well as the life quality. However for $\beta = \infty$, $K = \dot{H}$, and the individual is a perfect adapter. The stock condition is then:

$$(28)\quad g_t(r + \delta_t - \frac{\dot{g}_t}{g_t}) = \frac{1}{\mu_t}\left[\gamma_t h'(H_t) - U'_{\dot{H}}(C_t, \dot{H}_t)\delta_t e^{-y_t}\right]$$

As before, an increase in health increases expected lifetime, and the first term in the parentheses is positive. However, the second term is negative: a higher stock of health means a higher depreciation and thus a higher fall in future health. Therefore, for the perfect adapter, MEC may be positive or negative depending on which effect is the largest.

4. NUMERICAL RESULTS

There are several difficulties in characterising optimal paths and conducting comparative dynamics in a continuous time model with four stock variables (see also paragraph 4.3 below). For this reason we apply a numerical version of the model to explore the impacts of adaptation on health stock and medical care.

The model specification and parameter values are given in Appendix 1. Some important assumptions are, however; (i) an additive utility function in consumption and health, and (ii) a Weibull distribution to characterize the hazard rate function. The calibration of the benchmark scenario with no adaptation (GMEN, Grossman Model ENdogenous hazard) was conducted in order to reach realistic age profiles for the health variables, consumption, as well as for the contingent probabilities for the occurrence of death. Health stock and consumption paths are calibrated to reach their maximal values at young ages (30) and the mid-phase of life (50), respectively. The first is an assumption, while the second is based on empirical evidence from the US and the UK (Attanasio and Banks, 1998), see also footnote 7. To reach a realistic development in the contingent probabilities for the occurrence of death, we calibrated the model to reproduce a realistic expected length of life estimate for an individual living in an industrialised country; see, e.g., SSB (2000).

The model is optimised for a horizon of 140 years, using 10-year periods, however, we restrict our graphical presentations to the first 100 years only. Simulations were carried out using the GAMS/MINOS system (Brooke et al. 1992), and the GAMS code is given in Appendix 2.

4.1 THE ROLE OF HAZARD FUNCTIONS

Modelling life-termination as a stochastic decision (hazard function approach) represents an improvement to former approaches. For this reason, we start with simulations showing the role of mortality-risk being an object of choice. Figure 2 describes the optimal health stock paths in our version of the pure consumption model of Grossman (β = 0) for two different assumptions. The dotted line represents the model with the hazard rate being a decreasing function in health (GMEN), while the straight line represents a model where the hazard function is exogenous (GMEX, Grossman Model EXogenous hazard). This scenario is designed by feeding the hazard probabilities, determined in GMEN, exogenously into the model and then re-optimising. In this way we end up with a model where health still affects the quality of life, but without any possibilities to demand expected life-extension (quantity of life). By comparing model runs in GMEX and GMEN, we derive information on the separate role of health as a life-quality provider, and as a means to postpone expected death.

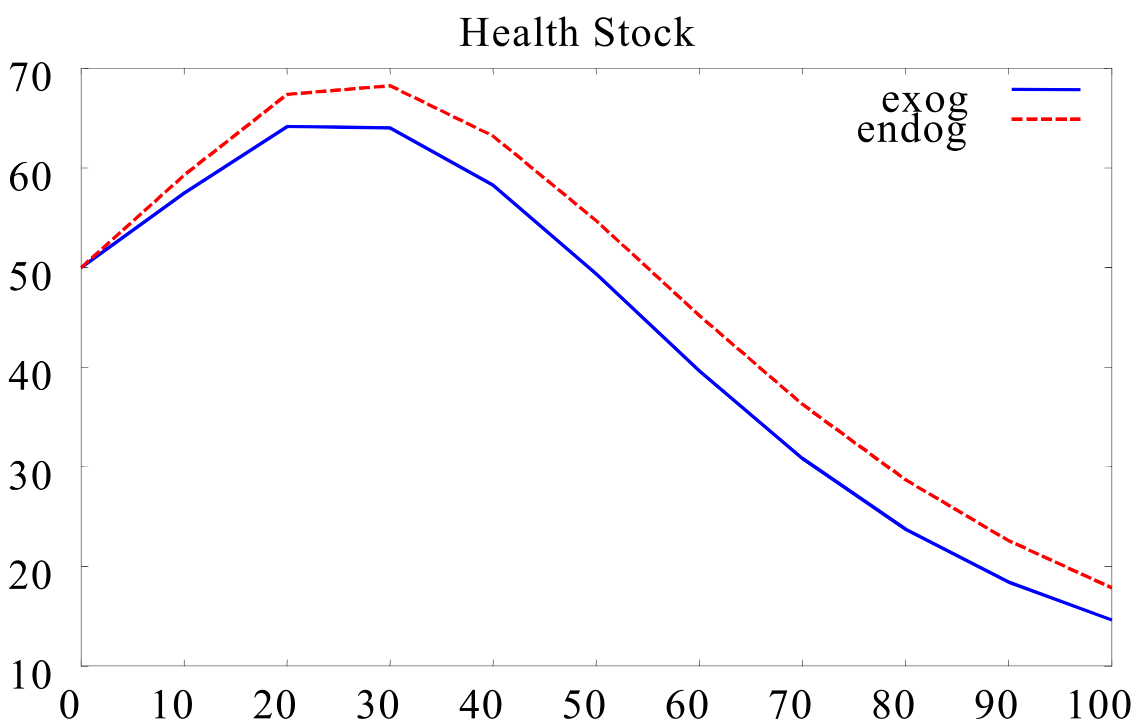

Figure 2: Optimal health stock paths for the pure Grossman consumption model (β = 0) with endogenous and exogenous hazard functions.

The two paths presented in Figure 2 envisage similar shapes, but GMEX yields lower health stocks at any date compared to GMEN. This is as expected since an exogenous hazard rate means lower returns to health investments relative to a situation where investing in expected life-extension is an option, se equation (26). The optimal stock of health increases gradually in the first phase of life for then to decrease as the individual becomes older (inverted U). This finding is inconsistent with some conclusions in the literature on the pure consumption model of Grossman, where a unique negative relationship between age and health is identified (see Zweifel and Breyer, 1997, and the references therein). However, we can quite easily identify a monotone declining relationship between age and health stock in the numerical model by, e.g., assuming a sufficiently high initial endowment of health.[17] Thus, our model allows for several possibilities as concerns the optimal health stock path, but a converted U seems realistic.[18] A similar result is found in Grossman (1972b), where health stock, in the first phase of life, is found to increase with age for a positive interest rate (r) and a health depreciation effect that increases with age.

In Figure 3, the developments in the use of medical care (I) for the two models are presented. Surprisingly, the two paths turn out very differently. For GMEN, the use of medical care is more or less stable (initial decline) the first decades, then rapidly increasing, and finally undergoing a sharp decline in the last phase of life (inverted U). The top is at 60 years. The reason why the use of medical care is falling at high ages, is that the individual does not expect to live that long - the expected lifetime in GMEN is 73.9 years[19] - and he prefers to spend the money on consumption at earlier stages of life instead. In GMEX, on the other hand, the path is gradually declining throughout life. Hence, choosing an exogenous rather than an endogenous hazard function is important for the shape of the path for medical care. We observe, as expected, that the use of medical care are significantly lower at all ages in GMEX

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[17] For GMEN, a negative relationship is achieved by increasing H_0 by 300%.

[18] One indication of an increasing health in the first stage of life is a falling death rate (see, e.g., SSB, 2000, for Norwegian data).

[19] This is subject to that the individual dies before he turns 110. If the individual can live for 140 years, the expected lifetime is 79.5 years. In comparison, the expected lifetime for men in Denmark (1997) was 73.3 years; while it was 74.6 in France (1999), see SSB (2000). In the following we will only report the expected lifetime subject to death before 110 years.

compared to GMEN. At age 20 the reduction is about 75% and at age 60 the decrease amounts to 90%.

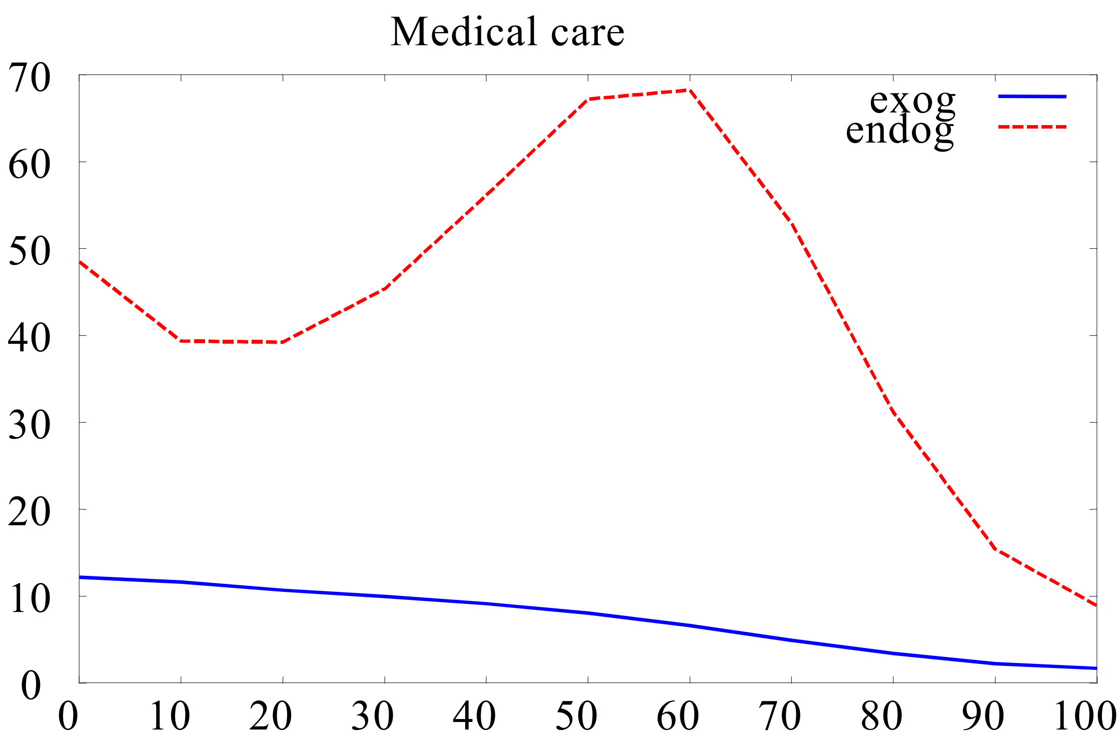

Figure 3. Optimal paths for medical care in the pure Grossman consumption model (β = 0) with endogenous and exogenous hazard functions.

The possibility to demand (expected) longevity does not only raise health investments but also affects the distribution of buying medical care over time by concentrating it to the mid-phase of life. Hence, considering health as a means of life-extension and not only as life-quality provider is important. In spite of the very different shapes of the two paths, both exhibit developments that are different from findings presented in Zweifel and Breyer (1997), where a positive theoretical relationship is identified between age and health investments. As this cannot be a general result,[20] it is of some

[20] As there is a positive transformation from medical care to health investments in our model, the development of medical care and health investments can be found from equation (9): $\dot{I}_t = \frac{H_t}{F'(I_t)}\left(\frac{\ddot{H}_t}{H} + \dot{\delta}_t + \delta_t \frac{\dot{H}_t}{H_t}\right)$. Thus, health investments are falling if the term in the parenthesis on the right hand side is negative, and increasing if it is positive. While $\dot{\delta}$ is always positive, first and second order derivatives of the health stock vary over time, and health investments may fall or rise when the health stock is increasing as well as decreasing.

interest since many implications of the Grossman model (consumption model as well as the investment model) are being contradicted by available empirical evidence (see Zweifel and Breyer, 1997, for an overview).

4.2 THE ROLE OF ADAPTATION

We now turn to the impact adaptation processes may have for health-related decision-making. The model with an endogenous hazard function is considered for three different values of β; $\beta = 0$ (no adaptation), $\beta = 1$ (some adaptation) and $\beta = \infty$ (perfect adaptation). From Figure 4 it follows that adaptation has a modest impact on the optimal stock of health compared to the effects of different hazard functions (see Figure 2). Parts of the explanation lie of course with the fact that health investments are heavily motivated by life-extension motives which are not subject to adaptive processes. However, it turns out that the impact on the health stock from adaptation is relative modest also when compared to the effects arising from shifts in exogenous variables of the model, see paragraph 4.3 below. Furthermore, an increasing degree of adaptation (a higher β), yields the most significant downward shift (in both absolute and relative terms) in the mid-phase of life, while the optimal health path is almost catching up again late in life. With adaptation, the expected lifetime falls from 73.9 ($\beta = 0$) to 73.5 with $\beta = 1$, and 73.2 with $\beta = \infty$.

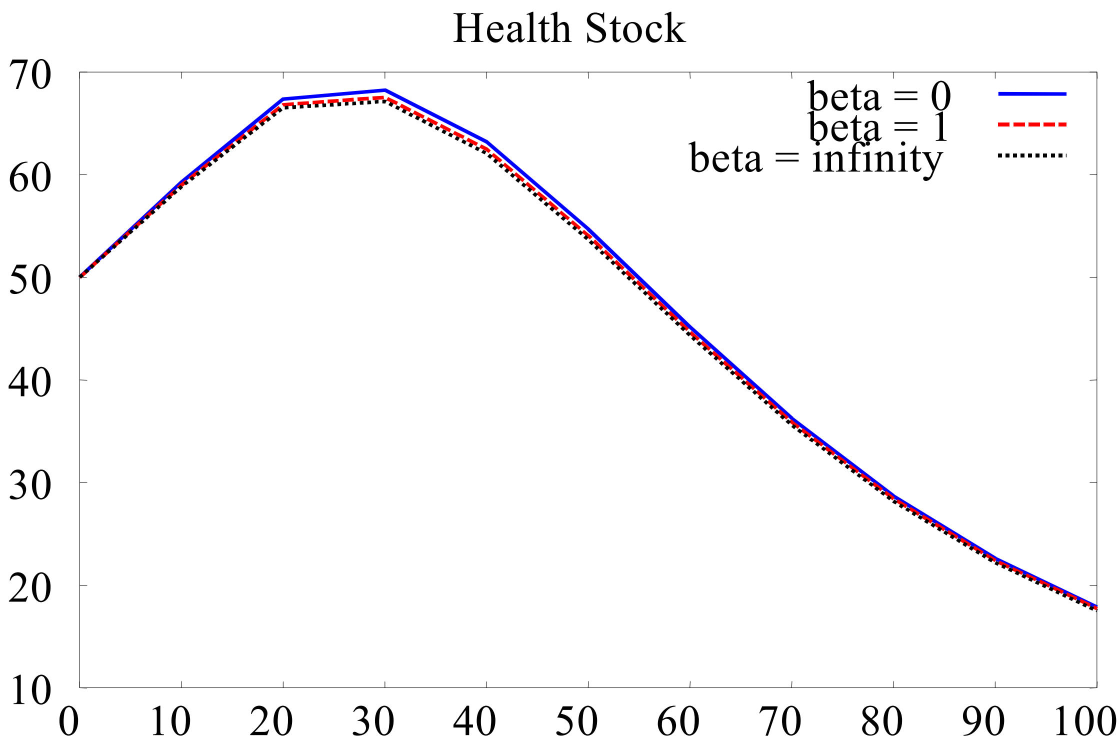

Figure 4. Optimal health stock paths for varying degrees of adaptation ($\beta = 0$; $\beta = 1$; $\beta = \infty$) in a model with an endogenous hazard function.

Figure 5 presents the effects on medical care use from an increasing degree of adaptation. Also for this variable, the magnitude of the shift differs somewhat over time. In both relative and absolute terms, the shifts are most significant in the first and mid-phase of life, while they become weak and almost insignificant at an advancing age. With perfect adaptation, the use of medical care decline roughly by 30% in the first phase of life, and by about 10-15 % in the mid-phase. The reductions observed in medical care and health stock over time make evident that adaptation, as formulated in this paper, lowers the incentives for investing in health. This effect is not surprising in view of the discussion around the stock conditions in paragraph 3.5 above.

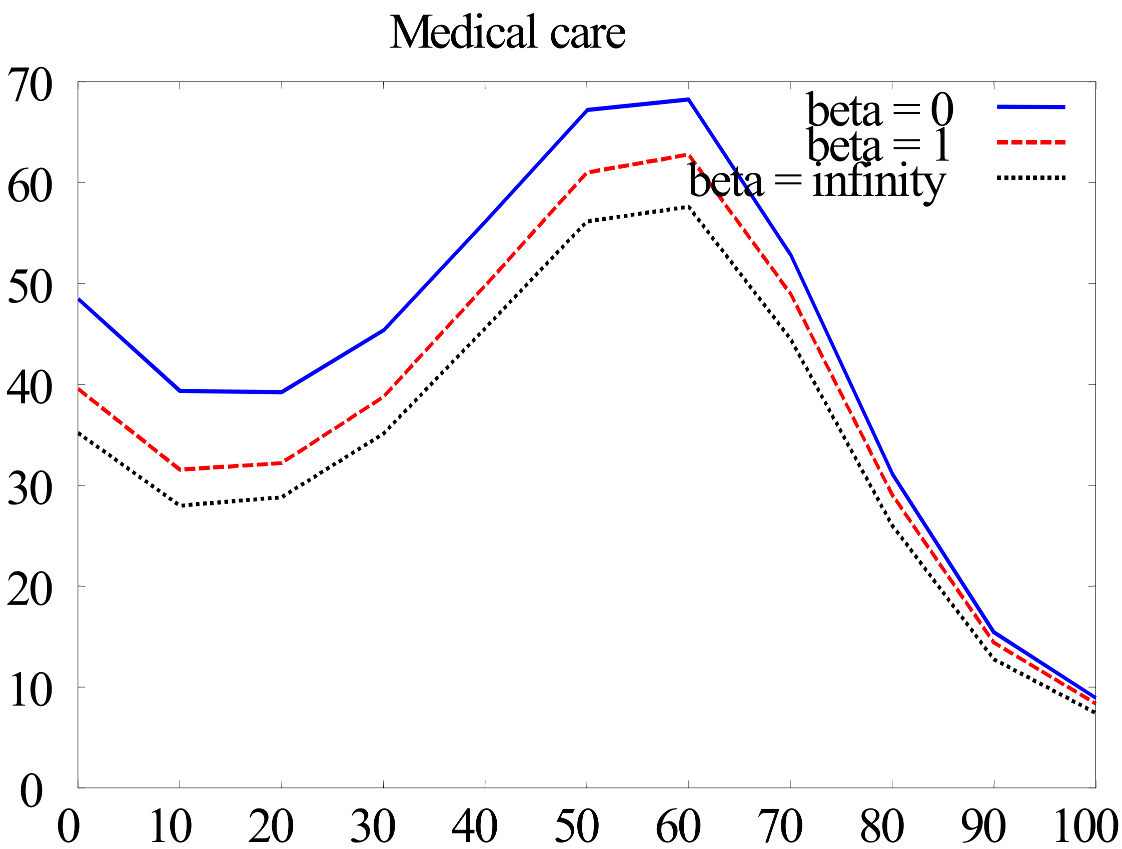

Figure 5: Optimal paths for medical care for varying degrees of adaptation (β = 0; β = 1; β = ∞) in a model with an endogenous hazard function.

The fact that the magnitude of shifts changes over the planning horizon in response to adaptation for both health variables deserves more attention. We already know from Figures 4 and 5 that path deviations appear almost insignificant late in life (in absolute terms) compared to the pure Grossman consumption model (GMEN). For the stock of health, the most significant downward shifts occur in the mid-phase of life, while for medical care the shifts are most significant in the first phase of life (30% at age 20 and 10% at age 60 for $\beta \to \infty$). These findings are somewhat different from those arrived at when comparing the same two variables in Figures 2 and 3. Here, the differences in health stock are found to increase steadily over time, both in absolute and relative terms. For medical care, the gap between GMEX and GMEN increases rapidly until age 70, for then to be reduced. Thus, a decline in returns to health investments is not the only impact that arises in response to adaptation processes.

Adaptation processes as well as the absence of possibilities to demand (expected) life-extension make health and hence health investments less attractive, however their impact on health decision-making differ. The presence of adaptation triggers behaviour that smoothens the optimal health stock path over time, i.e., the path becomes flatter. This effect is best illustrated by the case of perfect adaptation ($\beta = \infty$), for which the immediate health stock change is the only health-related argument in the utility function. The build-up of health at early dates involves costs later in life, since future falls in the stock due to increased depreciation are unavoidable. This effect, ceteris paribus, gives a smoothening incentive for the development of the health stock over time**.** The optimal consumption path shifts upwards in response to adaptation for the first 60 years, suggesting that adaptation makes health less attractive relative to consumption. However, the peak identified at age 50 in the benchmark scenario (GMEN) remains.

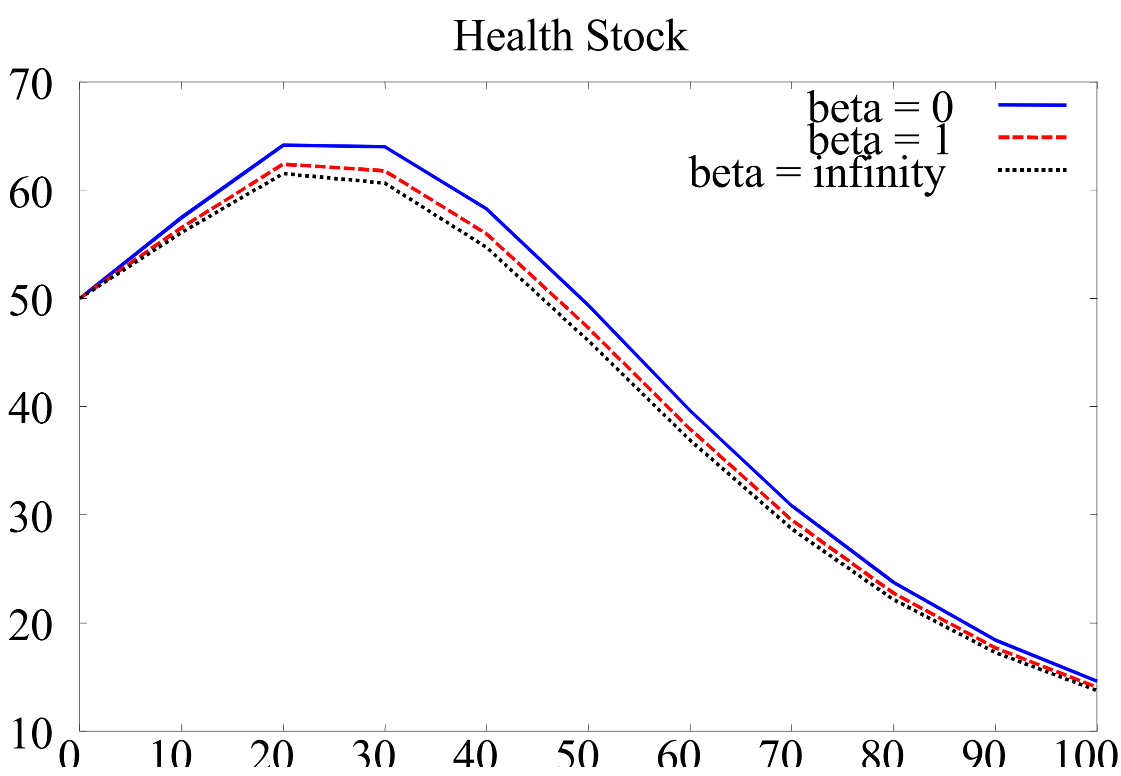

Figure 6: Optimal health stock paths for varying degrees of adaptation ($\beta = 0$; $\beta = 1$; $\beta = \infty$) in a model with an exogenous hazard function.

Figure 6 also sheds light on the role of adaptation processes, but now for the model with an exogenous hazard function. Adaptation has much the same impacts as the ones identified for an endogenous hazard function. As before, a higher degree of adaptation causes a downward shift in the stock of health over time, and the magnitude of the shift, in absolute terms, gradually increases in the first phase of life, for then to become smaller at later dates. Late in life, the paths almost converge. However, the presence of adaptation processes has a more significant effect on health compared to the case with an endogenous hazard function. This finding is self-evident as all health-improving motives are now subject to adaptation processes.

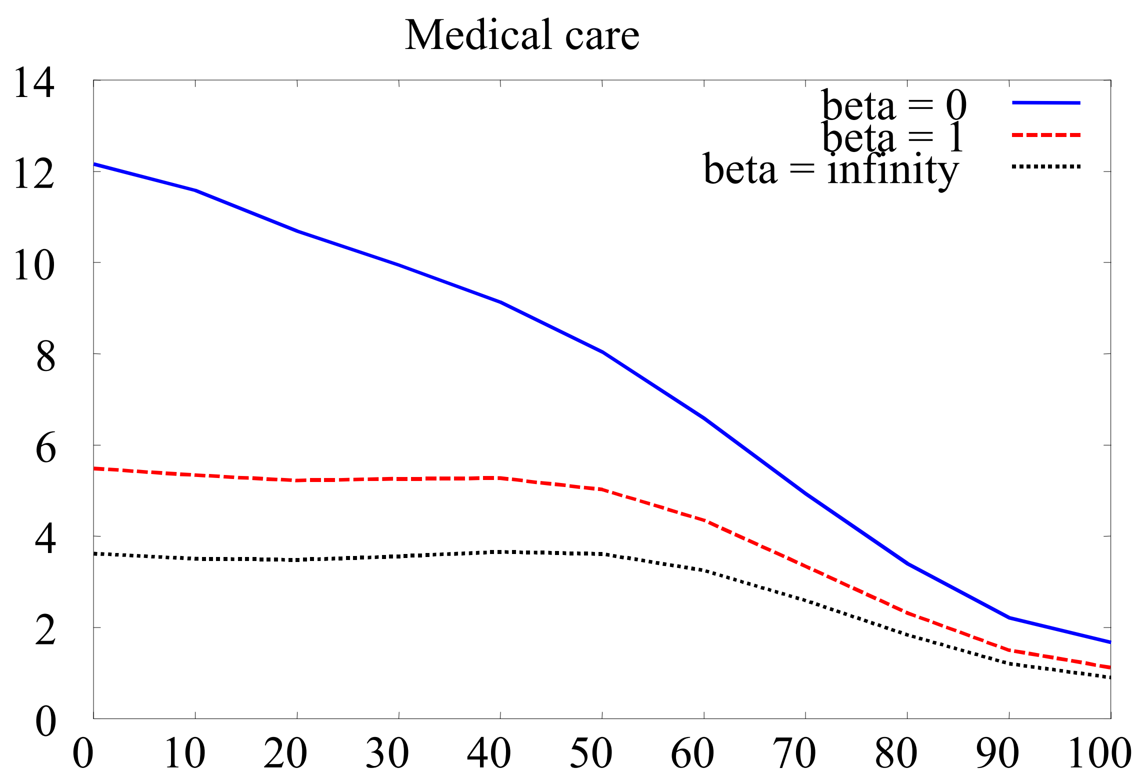

Figure 7: Optimal paths for medical care for varying degrees of adaptation ($\beta = 0$; $\beta = 1$; $\beta = \infty$) in a model with an exogenous hazard function.

The optimal paths for medical care are presented in Figure 7. We already know from Figure 3, that the path in GMEX exhibits a development different from the one in GMEN. However, as seen from Figure 7, this fact does not change the impact from adaptation. Adaptation now triggers a downward shift in the path for medical care, and the shifts are, both in absolute and relative terms, very significant early in life (60% at age 20 and 50% at age 60 for $\beta \to \infty$) while they become relatively weaker at the end of the life cycle. However, adaptive medical care paths are not necessarily steadily declining over time, as was the case for $\beta = 0$ in Figure 7. The smoothening of the paths for medical care identified seems to follow from the need to smoothen optimal health stock paths in response to adaptation.

To sum up, we have identified two effects arising from adaptation. First, adaptation lowers the rate of return to health investments yielding both lower use of medical care and lower stocks of health at any date throughout the planning horizon. Second, adaptation represents an incentive to smoothen health stock paths. For the model version with an exogenous hazard function, such a change of behaviour induces a smoothening of the medical care path as well, while for the model version with an endogenous hazard this is not the case. The above discussions have also shown that the assumptions made about life-termination have important implications for health-related decision-making.

4.3 COMPARATIVE DYNAMICS

There is a debate in the literature on the proper methodology to conduct comparative dynamics in models with several stock variables (see, e.g., the discussions in Ehrlich and Chuma, 1990; Ried, 1998; Eisenberg, 1999).[21] This fact, together with modifications of the basic model of Grossman, makes it somewhat confusing to review and compare the theoretical predictions arrived at across studies.

In the following we present the behavioural implications concerning the effects of exogenous variables in our model (comparative dynamics). The effects on optimal paths over the life cycle are derived from numerical simulations. In Table 1 we only

[21] Ehrlich and Chuma (1990) challenge some of the methodology applied by Grossman (as well as subsequent works see Muurinen, 1982; Wolfe, 1985 and Cropper, 1977) with respect to model specification (linear Hamiltonian) and the transversality conditions applied. See also Grossman (1998). Eisenberg (1999) and Ried (1998) do not find Ehrlich and Chuma's application of Oniki's (1973) path analysis satisfactory for problems with more than one stock variable. Ried (1998), which appear to represent the most satisfactory approach, applies Frisch decision functions in a discrete version of the full Grossman model to undertake comparative dynamics. Here, the direction of most effects analysed remain ambiguous, however, some effects become definite for the pure investment model only.

present the results from our version of the pure Grossman consumption model (GMEN), since comparative dynamics in the model versions with adaptation did not give significant differences relative to GMEN, with the exception of shifts being slightly weaker, in particular for consumption and medical care paths.

As follows from Table 1, higher initial wealth (A_0) yields a unique positive shift for the optimal paths of health stock, medical care, as well as consumption. Furthermore it is seen that the probability of life-termination, undergoes a unique downward shift. The conclusions coincide with the ones derived for a higher exogenous income at all dates (Y). However, a higher income from 70 years onwards (2/3 of previous income), did not change results much as the expectations of living are low. These results are all more or less as expected, in that additional financial resources increase both the demand for consumption and health. However, this is different from the conclusions reported in Zweifel and Breyer (1997) on the pure Grossman consumption model, as concerns the effect of lifetime wage on health stock and health investments (negative relationship).[22]

Table 1: ***Comparative dynamics predictions (GMEN).***

	Exogenous variables[a]						
Endogenous variables	**A_0**	**H_0**	**Y**	**q**	**ρ**	**r**	**δ**
H_t	+	+	+	÷	÷	÷/+	÷
I_t	+	÷/+	+	÷	÷	÷/+	+/÷
C_t	+	÷/+	+	+/÷	+/÷	÷/+	+/÷
$(1-e^{-y(t)})^b$	÷	÷	÷	+	+	+/÷	+

Note: The signs and their sequence describe the direction of the shifts in paths for the respective endogenous variable. (+) implies an increase in the endogenous variable for all t, while (÷/+) means a phase with lower values first and a later phase with higher values.

[a] A_0 is increased by 100%, q by 50%, and Y by 20% (100% late in life) compared to the benchmark scenario (GMEN). H_0 increases with 50%, ρ increases from 3% to 4%, r from 4% to 5%, while δ increases with one additional percentage point throughout the horizon of the model as compared to GMEN.

[b] $(1-e^{-y(t)})$ is the probability of life-termination until date t seen from the initial date, i.e., a negative shift means a higher expected lifetime.

[22] This conclusion is somewhat surprising in view of theoretical modelling being more general approaches than our numerical model.

A higher unit price on medical care (q) and a higher time preference rate (ρ) induce the same direction of shifts. Health investments are lower at all dates, consequently the health stock becomes lower, the probability for life termination becomes higher, while optimal levels of consumption are higher in early years but lower at older ages. A higher time preference rate is expected to increase the demand for consumption at early dates at the expense of the same demand later in life as well as for health. This is confirmed, however, the negative impact on medical care use early in life is quite weak but increases rapidly over time. Later in life, however, the gap narrows, most probably it can be attributed to the strong impact demand for longevity has in our numerical model. Grossman (1972b) finds that a lower time preference rate will prolong the initial time interval, for which health is increasing, however, the specific change undertaken in Table 1, turns out to be insufficient in reaching the same conclusion.[23]

For a higher q the downward shift in medical care use is stable during the first and mid-phase of life, an observation being consistent with substitution of health with consumption in these periods of life. However, consumption is lower late in life, most probably being a result of the priority given to health investments in postponing death. A rather interesting observation is that adaptation induces shifts being similar to the ones derived for q and ρ. All induce lower medical care use over time, while consumption increases somewhat relative to the baseline scenario the first decades for then to become lower from mid-life and onwards. However, the convergence in the health stock path at old ages observed in models with adaptation is absent for shifts in q and ρ.

A higher market interest rate (r) has more complex effects on the time profile of the endogenous variables. The paths for medical care and consumption are lower at early dates since returns to saving have increased, while additional financial resources available in the future increase both health and consumption at later dates. The same matters for medical care and consumption paths when an increase in the initial

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[23] A time preference rate of 3% may be high, but it turns out that this rate is crucial for determining the optimal consumption path. We calibrated the model for a consumption peak at around 50 year based on Attanasio and Banks (1998). With a lower time preference rate, the peak of the consumption path will be later in life.

endowment of health (H_0) is undertaken, while the exact opposite relationship is observed for an (continuous) increase in the health depreciation rate (δ). As concerns a higher H_0, marginal returns to health investments become lower. In order to keep health investment and thus the health stock relatively high from mid-life onwards, it becomes optimal to intensify saving early in life rather than to consume more. A higher rate of health depreciation (δ) skews medical care in favour of early health investments at the expense of late investments. However, the increase in medical care that takes place in the first period of life is not sufficiently strong to prevent the health stock itself from becoming lower in the first phase of life. A rather interesting observation is that the shifts induced by higher health depreciation rates are similar to the shifts induced by adaptation. The downward shift in health stock is most significant, absolute and relative, in mid-life, while late in life it tends to catch up with the optimal health stock path for lower depreciation rates. In this perspective, higher health depreciation rates also induce a smoothening of the optimal health stock path.

4.4 SENSITIVITY ANALYSES

As the parameterisation of the model is subject to discussion, sensitivity analyses are needed. Therefore, we made sensitivity analyses on the utility function, the investment function, and the hazard function.

Increasing the weight on consumption on the expense of health in the utility function, gives negligible impacts of adaptation, while the opposite is the case for an increased weight on health. In the latter case, we get quite high positive impacts on medical care use, a lower consumption path (peak at 60 years) and a lower death probability.

We assume a constant productivity of medical care in the health production function. Decreasing the productivity over time, i.e., as the individual gets older, gives negligible impacts on the health stock and the consumption path, but the path of medical care use will shift somewhat to the left, and the expected lifetime will slightly fall. Increasing the overall productivity by increasing the exponent in the investment function (as well as adjusting the hazard function to get a reasonable development of the death probability), gives high effects of adaptation. The health stock and medical care use increase, and consumption falls.

Changes in the hazard function to increase the probability of dying, gives different changes in the paths dependent on which parameter is changed. But overall, the results do not provide much new information.

To sum up, model runs show that the impact from adaptation increases for higher returns to medical care, by improving the weight of (subjective) health at the expense of consumption in the utility function, and by reducing the impact better health has on life-extension possibilities.

5. CONCLUSIONS

Our analysis links adaptation to ageing in the pure consumption model of Grossman with stochastic life-termination. We show that adaptation has two effects on health demand. First, the awareness of adaptation makes health investments less attractive, thus yielding a lower optimal health stock over time. Second, the same awareness gives an incentive for the individual to smoothen planned health stock paths. The effects of adaptation may, however, not be very high, as a main incentive for demanding health seems to be to prolong life. Furthermore, it follows that adaptation has effects on health, health investments, and consumption paths being similar to the effects that follow from a higher price on medical care and a higher time preference rate. However, the smoothening effect observed when analysing adaptation is absent for the same two variables, but show up for a shift in the health depreciation rate.

There is a discussion in the literature of the proper way of doing comparative dynamics in models with many stock variables. We have, therefore, conducted the analysis on a numerical model, and we show that the effects that arise for the joint development in health and health investments when undertaking comparative dynamics are not changing across models ignoring adaptation and those that do not.

As this analysis concentrates on the effect of adaptation on ageing, i.e., a continuous fall in health, several other interesting problems connected to adaptation is connected to abrupt changes in health. Also, adaptation as formulated in this work, may not capture all aspects of the phenomena as described in the literature. There is a lack of formal analyses on adaptation, and future work may provide additional insight.

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APPENDIX 1: Specifications and parameter values in the numerical model

The utility function is additive in consumption and health stock:

$$U_t(C_t, K_t) = (C_t + L_c)^{\alpha} + (K_t + L_K)^{\eta} \quad \textbf{(A.1)}$$

L_C and L_K are set equal to 100, and are included to allow for a negative K-value and to balance C and K. $\alpha = 0.4$ and $\eta = 0.6$.

The endogenous hazard function is specified as follows;

$$\dot{y} = \theta\varepsilon \left(\frac{1}{\left[\frac{H_t}{\omega}\right]^3 + 1} \right)^{\varepsilon - 1} \quad \textbf{(A.2)}$$

$\varepsilon = 2.5$, while $\theta = 0.02$ and $\omega = 37$ are calibrated to arrive at adequate death probabilities over the life horizon.

The health investment function is of the following type;

$$F(I_t) = dI_t^{\gamma} \quad \textbf{(A.3)}$$

where d is a constant equal to 1, while the power, γ, equals 0.1.

Initial endowments of health, H_0, and wealth, A_0, are 50 and 250, respectively. The market interest rate, r, is set at 4% p.a., the utility discount factor, ρ, is assumed to be 3%, while the unit prices of consumption (q) and medical care (p) are constant and equal to 1 in all periods. Annual income is 250 for the first 60 years, and 50 thereafter. The health depreciation rate, δ, varies over time and equals 1% the two first decades, for then to increase with 1 percentage point in every succeeding decade.

APPENDIX 2: The GAMS code

```
$title Adaptation model

OPTION NLP=CONOPT2

$setglobal betainf no
$setglobal endog 1

SET
   T     time periods   /0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140/;

PARAMETERS
  delta(T)      depreciation rate
  q(T)          price on medical care
  p(T)          price on consumption goods
  Y(T)          income
  EX_H(T)       Health stock path for exogenous probability runs  ;

  delta(T) = (0.01$(ORD(T) LE 2) + 0.01*(ORD(T)-1)$(ORD(T) GT 2));
  q(T) = 1;
  p(T) = 1;
  Y(t) = 250;
  EX_H(T) = 0;

* Change income path to reflect retirement (lower income after age 70)

  Y(t)$(ord(t) gt 7) = 50;
  Y(t)$(ord(t) eq card(t)) = 0;

SCALARS
  H0            initial health stock                          / 50 /
  A0            initial wealth                                / 250 /
  alpha         parameter in utility function (consumption)   / 0.4 /
  beta          parameter in utility function (health)        / 0.6 /
  kbeta         parameter in adaptation function              / 0 /
  gamma         parameter in health production function       / 0.1 /
  rate          market interest rate                          / 0.04 /
  pref          time preference rate                          / 0.03 /
  PAR1          parameter in hazard function                  / 0.02 /
  PAR2          parameter in hazard function                  / 2.5 /
  critical      parameter in hazard function                  / 37 /
  haz           endogenous probability flag                   / 1 /
  betainf       limiting adaptation case flag                 / 0 /
  lifetime1     expected lifetime                              / 0 /
  lifetime2     expected lifetime st. death before 110        / 0 /;
```

```
VARIABLES
  K(T)          adaptation function
  H_D(T)        change in health stock ;

POSITIVE VARIABLES
  C(T)          consumption
  I(T)          medical care
  H(T)          health stock
  A(T)          wealth
  LY(T)         integral of the hazard rate
  KUM(T)        probability of dying ;

FREE VARIABLES
  UTIL                 utility;

EQUATIONS
  UTILITY              intertemporal utility function
  H_FUNC(T)            health definition
  H_D_FUNC(T)          health transition
  A_FUNC(T)            wealth definition
  BUDGET(T)            period budget constraint
  K_FUNC(T)            adapted health good definition
  K_FUNC2(T)           adapted health good definition when kbeta is equal to infinity
  AHAZARD(T)           endogenous hazard function
  AHAZARD2(T)          exogenous hazard function
  KUM_FUNC(T)          probability of dying definition ;

H_D_FUNC(T).. H_D(T) =E= 0$(ORD(T) EQ 1) + (H(T) - H(T-1))$(ORD(T) GT 1);

H_FUNC(T).. H(T) =E= H0$(ORD(T) EQ 1) + (EXP(-10*delta(T-1))*H(T-1) +
(1/delta(T-1)*(1-EXP(-10*delta(T-1)))*(I(T-1)+0.00001)**gamma))$(ORD(T)GT 1);

A_FUNC(T)..  A(T) =E= A0$(ORD(T) EQ 1) + (EXP(10*rate)*A(T-1) +
(1/rate*(EXP(10*rate)-1)) * (Y(T-1) - q(T-1) * I(T-1) - p(T-1) * C(T-1)) )$
(ORD(T)GT 1) ;

BUDGET(T)..  q(T) * I(T) + p(T) * C(T) - Y(T) =L= A(T) ;

K_FUNC(T)$(not(betainf)).. K(T) =E= (H0/(1 + kbeta))$(ORD(T) EQ 1) +
(K(T-1)/(1 + kbeta) + (kbeta/((1+kbeta)**2))*H0 + H_D(T))$(ORD(T) GT 1);

K_FUNC2(T)$(betainf).. K(T) =E= H_D(T);

AHAZARD(T)$(haz).. LY(T) =E= 0$(ORD(T) EQ 1)+(LY(T-1)+
10 * PAR1*PAR2*(1/((H(T)/critical)**3+1))**(PAR2-1))$(ORD(T) GT 1) ;

AHAZARD2(T)$(not(haz)).. LY(T) =E= 0$(ORD(T) EQ 1)+(LY(T-1)+
10 * PAR1*PAR2*(1/((EX_H(T)/critical)**3+1))**(PAR2-1))$(ORD(T) GT 1) ;

KUM_FUNC(T).. KUM(T) =E= 1 - EXP(-LY(T));
```

```
UTILITY.. UTIL =E= SUM(T, EXP(-LY(T))*EXP(-(10 * pref)*(ORD(T)-1))*((C(T)
+ 100)**alpha + (K(T) + 100)**beta));

MODEL
  HEALTH /ALL/;

OPTION ITERLIM = 25000, RESLIM = 5000;
HEALTH.OPTFILE = 1;

  I.LO(T) = 0 ;
  C.LO(T) = 0.0001 ;
  A.LO(T) = 0 ;
  H.LO(T) = 0.0001 ;
  KUM.UP(T) = 1.0 ;
  H_D.LO(T) = -99.9999 ;
  H.UP(T) = 10000000;
  K.LO(T) = -99.9999 ;

* Use the hazard function

        haz = 1;

SOLVE HEALTH MAXIMIZING UTIL USING NLP ;

lifetime1 = SUM(T$((ORD(T) Gt 1)$(ORD(T) le 15)),10*(ORD(T)-1)*(KUM.L(T)-
KUM.L(T-1)))/KUM.L("140");

lifetime2 = SUM(T$((ORD(T) Gt 1)$(ORD(T) le 12)),10*(ORD(T)-1)*(KUM.L(T)-
KUM.L(T-1)))/KUM.L("110");

Display lifetime1;
Display lifetime2;
```