Endogenous Health Care and Life Expectancy in a Neoclassical Growth Model*

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Abstract

We study the endogenous relationship between health care, life expectancy and output in a modified neoclassical growth model. While health care competes resources away from goods production, it prolongs life expectancy which in turn leads to higher capital accumulation. We show that savings and health care are complements in equilibrium, with both rising with economic development. Our model is therefore consistent with several stylized facts, namely, (i) countries spend more on health care as they prosper, (ii) individuals in rich countries tend to live longer, and (iii) population aging is more pronounced in rich countries. Moreover, through simulation, health care and health production technology are found to be growth and welfare enhancing.

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1 Introduction

With few exceptions, we have observed consistent and steady rises over time of health care expenditure, both in absolute terms and as percentages of GDP, in almost all countries in the world. The total health care expenditures among EMU countries, for example, have reached an average around 9% – a significant share – of GDP in recent years (see Table 1).[1] It is therefore not surprising that health care issues and policies have attracted growing attention in many, albeit mostly developed, countries. From macroeconomic point of view, both time-series and cross-country data have been suggesting a rather robust positive correlation between health care spending and per capita GDP. Simultaneously, we have also observed in the same process striking rises in longevity and transitions of demographic structure in economies across different stages of development (see again, for example, Table 1). Despite the seemingly overwhelming empirical evidence, there has been little theoretical work on modelling the explicit linkage between health care spending, life expectancy, and economic performance. In this paper, we formalize within a simple growth framework a mechanism through which health care expenditure and life expectancy endogenously evolve with economic development. In so doing, we intend to address the several patterns exhibited in Table 1 and, more generally, to explore some macro implications of health care in the process of economic development.

[Insert Table 1 about here]

In the growth literature, health usually plays a passive and dormant role as it is often proxied by, or identified with, life expectancy, and hence the study of its economic relevance is largely limited to investigating the growth implications of life expectancy. Along this line of research, Kotlikoff (1989) finds that life-extension is likely to raise capital and output per worker, as well as welfare. In an endogenous growth model with intergenerational trade, Ehrlich and Lui (1991) argue that an increase in longevity can stimulate growth through motivating human capital investment in future generations. The cross-country evidence presented in Barro (1997) also suggests that both the education attainment and the life expectancy are positively correlated with the growth rate of real GDP per capita. Indeed, the simulation of a calibrated model in Kalemli-Ozcan *et al* (2000) shows a significant role of mortality decline in raising human capital investment during the process of economic growth. In these studies, however,

[1] This table summarizes some key indicators of our interest from the World Development Indicators 2001 published by the World Bank.

life expectancy (or mortality) is treated as an exogenous parameter, and the linkage between health investment and life expectancy is not considered.

In this paper, we study the inter-dependence of health care/investment, life expectancy, and economic development in an overlapping generations model of two-period lived agents. Contrasting with the conventional model, we assume that individuals only survive to the second period (retirement age) with a probability that is increasing in their health capital. Following Grossman (1972), the stock of health capital can be maintained and/or augmented through purposeful health investment. In this environment, health investment gives rise to two opposing effects on capital accumulation and hence growth: While health investment directly diverts resources away from productive use, it results in a prolonged life expectancy which in turn encourages capital formation. Despite the direct competition for available resources, we show that aggregate savings/capital and health investment are complements along an equilibrium path – agents will optimally choose to increase or decrease savings and health spending at the same time. In our parametric example, we also show that health care is indeed a normal good under plausible parameter values. In addition, we show through simulation that the steady-state output, per capita income, and welfare in our model are consistently higher than those in a benchmark model where the role of health care in life extension is absent. This implies that health care is potentially a growth-promoting factor and the usual models that neglect health care tend to either under estimate growth/output or over estimate the growth impacts of other factors. Our simulation results further suggest that advancement in medical technology is also likely to raise steady-state output and welfare.

An important feature of our model is that life expectancy evolves endogenously with health care spending along an equilibrium path. This endogenous treatment of life expectancy in our model allows for the following implications on the demographic structure that are largely consistent with the stylized facts. In our model, health care spending and hence life expectancy are positively correlated with income. This suggests that, from the time-series point of view, life expectancy tends to rise as a country develops and, from the cross-country point of view, high income countries tend to have higher life expectancies than low income countries. These implications seem to accord well with the evidence in, for instance, Cochrane *et al* (1978), Parkin *et al* (1987), Gerdthan *et al* (1992), and Table 1. In addition, our model is also consistent with the observation that the percentage of population in retirement is higher in developed countries than it is in developing countries, as indicated in Table 1.

Health investment affects capital accumulation and growth in our model through changing life expectancy. It has been argued that an increase in life expectancy might exert a negative impact on per capita income, as extending lives beyond productive years would only lead to a greater population dependency ratio and a smaller per capita output. We turn this concern on its head in the present model: An increase in life expectancy takes precisely the form of a greater percentage of agents surviving to the second period of their lives during which they are no longer productive. Despite this age-structure effect, increases in life expectancy in our model are found to be associated with higher levels of per capita GDP. This suggests that, as life expectancy rises, the positive impact on per capita income arising from higher savings tends to be large enough to outweigh the negative impact arising from a greater proportion of unproductive population. This implication is therefore in agreement with the recent studies by Lee *et al* (2000) and Bloom *et al* (2002), which found significant positive relationships between savings and life expectancy in cross-country data.

Our paper is also related to the following studies. In efforts to endogenize longevity, Blackburn and Cipriani (2002) obtain multiple equilibria with varying degrees of longevity and growth rate by assuming an externality from human capital. Philipson and Becker (1998) present a partial-equilibrium analysis in which longevity and health investment are influenced by the availability of age-contingent claims. Using a different approach than ours, the recent work by van Zon and Muysken (2001) offers a rare example that explicitly incorporates health into an endogenous growth framework.[2] Moreover, our notion of health investment is akin to that of "life protection" in the models of Grossman (1972), Ehrlich and Chuma (1990), and Ehrlich (2000) on demand for longevity. Their models are, however, largely partial equilibrium in nature and not focused on macro development issues. Finally, while Blackburn and Cipriani (2002) also uses a survival probability from one period to the next, their survival probability is assumed to be affected by the level of human capital, not health investment, and hence the explicit role of health care in life extension is absent. To summarize, comparing with the existing literature, our paper introduces a dynamic general equilibrium model in which the macroeconomic implications of health care can be conveniently analyzed.

[2]In van Zon and Muysken (2001), the authors extend the basic Lucas (1988) framework to an environment in which health investment competes for time with activities in human capital accumulation and goods production. In general, despite the productivity- and welfare-enhancing role of health, they find that health correlates negatively with growth. In contrast, we study a decentralized model with overlapping generations where health production competes for output with consumption. In our model, health tends to be positively associated with capital accumulation and hence output.

The rest of the paper proceeds as follows. We outline the general model and discuss the equilibrium conditions in Section 2. In Section 3, for illustration purposes, we will study how health care relates to growth by using an explicit parametric example and simulation. Then, we offer some concluding remarks in Section 4. Finally, some technical proofs are contained in the appendix.

2 The Model

We consider a two-period overlapping generations model in which a continuum of identical agents with mass one is born in each period. Agents born in period t live to the old age (the second period) only with a probability p_t that is determined by their health stock.[3] Following Grossman (1972), agents are assumed to be able to produce health stock by purposeful health investment, according to a health production function. Suppose agents of all generations are endowed ex ante with an initial health capital h_0 in the first period of their lives. The health stock of a young agent in period t is then described by the following equation

$$h_t = h_0 + h(m_t) \tag{1}$$

where $h(m_t)$ measures the health creation by health investment of m_t and satisfies $h'(\cdot) > 0$, $\lim_{m\to 0} h'(m) = +\infty$, and $\lim_{m\to\infty} h'(m) = 0$. Health investment in our model can be broadly defined as all spending and activities related to improving the health stock of an agent, which includes but is not limited to spending on medical products and services. For a concrete and reasonable approximation, we later use health care expenditure as the proxy for health investment in our discussion on calibration and simulation. Therefore, without confusion, we use the terms of 'health investment' and 'health care' interchangeably throughout the paper.

We postulate that the probability of a generation t agent surviving to the second period is increasing in his health capital and is given by $p_t = \widetilde{p}(h_t)$. This survival probability function can be rewritten, using (1), as $p_t = \widetilde{p}(h_t) = p(m_t)$. Naturally, the function $p(\cdot)$ can be interpreted as some sort of production function whereby resources are spent to "produce" chances of survival into old age. As such, $p(\cdot)$ can be expected to exhibit the usual properties of a production function. Specifically, for analytical simplicity, we assume the following conditions:

[3] This surviving probability into the second period of an agent's life, during which the agent no longer works, can be conveniently thought as the surviving probability to age 65, the normal retirement age, in Table 1. This probability is obviously related negatively to the mortality rate and positively to the life expectancy of the population.

$0 \leq p(\cdot) \leq 1$, $p'(\cdot) > 0$, $p''(\cdot) < 0$, $\lim_{m \to 0} p'(m) = +\infty$, and $\lim_{m \to \infty} p'(m) = 0$.[4] Finally, the health stock of an agent will drop to zero and the agent dies by the end of the second period with certainty.

Agents' preferences are identical for all generations. The preferences in the first period are given by a strictly increasing and concave utility function $u(c)$, satisfying the Inada condition at zero. The utility function from the second-period consumption is given by $v(c)$ that satisfies the similar conditions and $v(\cdot) \geq 0$.[5] Therefore, for an individual agent of generation t, his expected life-time utility is given by

$$U(c_t^t, c_{t+1}^t) = u(c_t^t) + p_t v(c_{t+1}^t) \tag{2}$$

where c_t^t and c_{t+1}^t are the consumption levels of a generation t agent in periods t and $t+1$, respectively.

Agents of all generations are endowed with one unit of labor when they are young, which is then supplied inelastically in the labor market. By supplying labor, an agent who is born in period t earns a market wage rate, w_t, in the first period of his life. Having earned w_t when young, the agent has to decide on his first-period consumption, c_t^t; his amount of savings, s_t; and the amount of health care he wishes to purchase, m_t. Savings in period t, which become the physical capital in period $t+1$, yield a real rate of return of r_t. Since not all agents survive to the second period, we assume that there is a perfectly competitive and actuarially fair annuity market through which the total returns from the savings of those who are deceased before reaching their old age will be equally redistributed, in the form of a lump-sum transfer, to the remaining survivors within the same generation. Let $P_t \in [0, 1]$ denote the proportion of generation t agents, at the aggregate level, who survive to the second period. It is easy to see that the lump-sum transfer to a survived old agent is

$$\tau_t = \frac{(1 - P_t) s_t (1 + r_t)}{P_t}. \tag{3}$$

Because all agents are identical and the population of young agents is normalized to one,

$$P_t = p_t = p(m_t). \tag{4}$$

[4]To gain some understanding of the shape of $p(\cdot)$, we have examined the cross-country relationship between survival rate to age 65, or life expectancy, and health expenditure per capita using the data compiled in the World Development Indicators 2001 by the World Bank. The scatter plot based on the empirical data strongly support our theoretical specification of $p(\cdot)$.

[5]Normally, the utility function is not required to be positive. However, the possibility of death in the second period introduces one technical problem: If the utility from consumption can be negative (such as the case with logarithmic utility function) and the utility in the event of death is normalized to zero, agents then could prefer death to surviving. To avoid such a perverse situation, we require that the second period utility function be positive.

For the same reason, throughout the paper, we will not distinguish variables at the individual level from that at the aggregate level.

Therefore, the optimization problem of a representative agent of generation t is as follows. Taking w_t, r_t, and τ_t as given,[6] the agent chooses s_t and m_t in order to maximize the expected life-time utility given in (2), subject to the following constraints:

$$c_t^t = w_t - s_t - m_t \tag{5}$$

$$c_{t+1}^t = s_t(1 + r_t) + \tau_t \tag{6}$$

$$p_t = p(m_t) \tag{7}$$

On the production side, the aggregate output is characterized by a constant return to scale production function in capital and labor, so that the per-capita output can be written as $y_t = f(k_t)$, where k_t measures the capital-labor ratio and $f(\cdot)$ is strictly increasing and concave. Labor and capital are assumed to be priced competitively according to their respective marginal productivities. Therefore, the wage rate and the rate of return on capital are given by

$$w_t = f(k_t) - k_t f'(k_t) \tag{8}$$

$$1 + r_t = f'(k_{t+1}) \tag{9}$$

Without loss of generality, capital is assumed to depreciate completely in every period so that

$$k_{t+1} = s_t. \tag{10}$$

Finally, the initial capital stock is $k_0 > 0$. This completes the description of the model.

For the maximization problem of generation t agents, the first order conditions with respect to s_t and m_t are, respectively,

$$u'(c_t^t) = p(m_t)v'(c_{t+1}^t)(1 + r_t) \tag{11}$$

and

$$u'(c_t^t) = p'(m_t)v(c_{t+1}^t) \tag{12}$$

where c_t^t and c_{t+1}^t are given in (5) and (6). Equation (11) is the usual condition that requires the marginal rate of substitution between current and future consumption to be equal to the

[6] Since the transfer is assumed to be in a lump sum, agents view τ_t as a number that is independent of their individual savings decisions. However, our entire analysis goes through if agents are assumed to take into account the effect of their individual savings decisions on the amount of transfers defined by (3).

expected return on savings. Equation (12) captures the trade off between the marginal cost and marginal benefit of health care spending. By investing in health care, the agent foregoes the current consumption in exchange for an increased chance of survival in the second period.

Combining (11) and (12), we obtain

$$p(m_t)v'(c_{t+1}^t)(1+r_t) = p'(m_t)v(c_{t+1}^t). \tag{13}$$

Equation (13) gives the condition on how to allocate a marginal dollar towards savings versus health care. If a marginal dollar is allocate towards savings, the agent gains marginal utility from the expected gross return of the dollar. On the other hand, if the same dollar is allocated towards health care, it increases the *chance* of actually enjoying future consumption by $p'(m_t)$. Therefore, in equilibrium an agent will allocate the marginal dollar towards health care such that the utility gain from health creation just equals the utility loss from having less expected second-period income.

Therefore, a dynamic equilibrium path of the economy is characterized by a sequence of $\{m_t,\ s_t,\ k_t\}_{t=0}^{+\infty}$ that satisfies the first order conditions (11) and (12), plus that equations (3) – (10) hold. Hence, in equilibrium, the first-period and second-period consumptions can be rewritten as

$$c_t^t = f(k_t) - k_t f'(k_t) - s_t - m_t \tag{14}$$

$$c_{t+1}^t = \frac{s_t f'(s_t)}{p(m_t)}. \tag{15}$$

Before we proceed, we make the following assumption.

Assumption A. $f'(k) + kf''(k) > 0$.

Assumption A means that at the total return of capital increases as the amount of capital in production increases. This is true, for example, for a Cobb-Douglas or a CES production function. Under this assumption, we prove in the appendix that the following result holds.

Proposition 1 *In equilibrium, the amount of savings* s_t *and the health investment* m_t *are strictly positively related.*

Proposition 1 implies that, despite the direct competition for resources, savings/capital and health investment are complements in equilibrium. The reason that in our model agents save more when health investment increases is two fold. As a higher health investment prolongs an agent's life expectancy, he has more incentive to save for the old-age income. Secondly, as health investment becomes higher, its marginal benefit diminishes (since $p(\cdot)$ is concave) and hence saving becomes a more attractive alternative.

Proposition 1 is also suggestive of the relationship between health care in economic development. Based on Proposition 1, one may reasonably conjecture that as the economy develops agents will spend more on health care, which in turn leads to more savings that could fuel further growth. Unfortunately, we could not establish such kind of result analytically in our model with the general functional forms. To gain better understanding of the role of health care, we specify in the following section the explicit functional forms in the model.

3 Health Care and Economic Growth

In this section, we assume the following functions:

$$u(c) = v(c) = \frac{c^{1-\gamma}}{1-\gamma} \tag{16}$$

$$f(k) = Ak^{\alpha} \tag{17}$$

$$p(m_t) = p_0 + \overline{p}\sqrt{\frac{m_t}{1+m_t}} \tag{18}$$

where the restrictions on the exogenous variables are $A > 0$, α, γ, $p_0, \overline{p} \in (0,1)$ and $p_0 + \overline{p} \leq 1$. The functional forms for the utility and output production are fairly standard.[7] The health production as embodied in the function $p(\cdot)$ allows for the following interpretations. The survival probability will be equal to p_0, which is strictly between 0 and 1, if an agent spends nothing on health maintenance. This default survival probability presumably reflects the innate health capital that everyone is born with. However, an agent can augment his chances of survival by purchasing and consuming health services, according to an increasing, concave health production function. In addition, $p'(0) = +\infty$ so that positive amount will be spent on health care in equilibrium, and the survival probability tends to $p_0 + \overline{p}$ as the health investment tends to infinite. Here, $\overline{p}$ can be interpreted as measuring the state of medical technology: An increase in $\overline{p}$ not only makes health production more effective, it also raises the maximum amount of life extension achievable through health investment.[8]

[7] We choose $\gamma < 1$ in the utility function in part because of the technical problem that we discussed earlier with negative utilities. This type of utility function with $\gamma < 1$ is commonly used to imply a positive interest rate elasticity of savings. Our results in this section, including simulation, are qualitatively the same if we assume some alternative functions for $u(\cdot)$ and $v(\cdot)$, such as a logarithmic function for $u(\cdot)$ and a linear function for $v(\cdot)$.

[8] Therefore, an increase in $\overline{p}$ can be thought as capturing both improvement on conventional treatment as well as discovery of new treatment.

Under the above specifications, equation (13) becomes

$$p(m_t)(1+r_t)\left(c_{t+1}^t\right)^{-\gamma}=p'(m_t)\frac{\left(c_{t+1}^t\right)^{1-\gamma}}{1-\gamma}.$$

Utilizing (9), (10), and (15), we have

$$s_t=(1-\gamma)\frac{p(m_t)^2}{p'(m_t)}\equiv s(m_t). \tag{19}$$

Since $p(m_t)$ is increasing and concave, it is clear that $s(m_t)$ is an increasing function, confirming the claim in Proposition 1. With the utility function given in (16), making use of (14) and (15), the first order condition (11) becomes

$$\frac{1}{[f(k_t)-k_tf'(k_t)-s_t-m_t]^{\gamma}}=p(m_t)^{1+\gamma}\frac{f'(s_t)^{1-\gamma}}{s_t^{\gamma}} \tag{20}$$

where $f(\cdot)$ and $p(\cdot)$ are given by (17) and (18), respectively. The following result establish a link between health care and per-capita income.

Proposition 2 *In equilibrium, health investment m_t is a normal good, that is, it is increasing with respect to wage income w_t and capital labour ratio k_t, if $\alpha<1/2$.*

We again refer the readers to the appendix for the proof. The parameter α represents the share of capital income in total output. The widely-cited value for α in the empirical literature is around one third or ranges from 0.25 to 0.4 (see, e.g., Mankiw, Romer, and Weil, 1992). Therefore, $\alpha<1/2$ is hardly a restriction. Several implications follow from Proposition 2. First, it confirms the empirical studies mentioned in the introduction that health care is indeed a normal good. Thus, as a country prospers, health care sector expands. Second, since the life expectancy increases with the health care spending, Proposition 2 implies that rich countries have longer life expectancy than poor ones. This prediction accords well with the empirical evidence (see Table 1). Third, population aging emerges in our model as a by-product of the process of economic development. As our model economy develops, agents consume more health care services and hence a greater percentage of the population survives to their old age, leading to population aging. While the association of population aging and economic development has been widely observed (see, again, Table 1), our explicit channel of health care in a dynamic general equilibrium framework is new.[9]

[9] We should add that it is not our position to suggest that this is the only, or even the most important, operative channel for observed population aging. For example, many studies have associated population aging with falling fertility.

One of the key questions that we would like to investigate with the present model is the overall effect of health care in the process of economic growth: Does health care promote or retard output? Health care consideration is typically absent in various neoclassical growth models. We can gain some understanding of the impact of such omission in conventional models, as well as the effect of health care on growth, by comparing our model with a benchmark model that is otherwise identical except without the health care sector. In our model, the equilibrium dynamics are determined by the initial per-capita capital stock k_0, (10), (19), and (20). A steady state of this economy is then characterized by $s_t = k_t = k$ and $m_t = m$ for all t. Under certain regularity conditions, it can be shown that the dynamics of this economy always converge to a unique steady state.[10] In the absence of the health care sector, the health investment is forced to be zero, i.e., $m_t = 0$, and hence the survival probability is constant $p_t = p_0$. Equation (20) then becomes

$$\frac{1}{[f(k_t) - k_t f'(k_t) - s_t]^\gamma} = p_0^{1+\gamma} \frac{f'(s_t)^{1-\gamma}}{s_t^\gamma} \tag{20'}$$

Thus, the equilibrium dynamics in the benchmark model are determined by the initial per-capita capital stock k_0, (10), and (20′). It can be shown that this benchmark model has a unique, globally stable steady state. The question of whether the steady state output in our model with health care is higher than that in the benchmark model is in fact not trivial: Although Propositions 1 and 2 establish a positive interaction between health care and capital accumulation, health care spending on the other hand diverts resources from goods production and hence lowers the potential output in the economy. To see which effect of health care will dominate in the long run and other comparative statics, we now turn to simulation.

3.1 Simulation

We choose the following parameter values in our base case simulation: $p_0 = 0.2$, $\overline{p} = 0.6$, $\alpha = 1/3$, $\gamma = 0.5$ and $A = 10$. The choice of the base case value of $\alpha = 1/3$ is based on widely-cited empirical estimate of the income share of capital, such as in Mankiw *et al* (1992). In our model, the probability p_0 measures the default likelihood of surviving to old age when health care spending is nil. This can be approximated by the surviving probability to age 65 (the retirement age) in the poorest countries. Since, according to the World Bank Development Indicators 2001, this probability in some poorest countries ranges from 0.2 to 0.4 (for example,

[10] For instance, these properties of uniqueness and stability of the steady state always hold for the ranges of various parameter values that are used in our simulation exercise.

this probability for Sierra Leone is 0.22), we choose $p_0 = 0.2$ for our base case. In addition, given that the world-wide surviving probability to age 65 is around 0.70 according to the same source, $\overline{p} = 0.6$ seems to be a reasonable starting point.[11] The other parameter values are chosen somewhat arbitrarily and calibrated only to the extent that the range of the resulting steady-state share of GDP in health care matches that observed in Table 1. We will, however, perform sensitivity checks with respect to the parameter values for robustness.

We will primarily conduct two kinds of simulation exercises with our model. First, we want to study whether our model with endogenous health care spending leads to higher or lower steady-state per capita income and welfare, comparing with the conventional model in which the role of health care in reducing mortality is absent. Second, we would like to examine how changes in medical technology (as measured by $\overline{p}$) affect, both qualitatively and quantitatively, the steady state values of endogenous variables such as per capita income, welfare, health care expenditure, and survival probability to retirement age.

Our simulation results are summarized in Table 2. The first column simply shows the different values of $\overline{p}$, which is the proxy for the state of medical technology, we use in simulation. The second and third columns simply show the corresponding steady-state values of total health care expenditure as percentage of GDP, $m/f(k)$, and survival probability, $p(m)$, respectively. In the fourth column, since young agents are the only workers in the economy, GDP per worker is simply measured by $f(k)$ in the steady state. By including the old people in the economy who are not in the labor force, the fifth column calculates the GDP per capita by $f(k)/(1+p(m))$. Finally, the sixth column shows the (expected) steady state welfare measured by $u(c_1)+p(m)v(c_2)$, where c_1 and c_2 are the first- and second-period consumption levels of an representative agent in the steady state. The corresponding values of GDP per worker, GDP per capita, and welfare for the benchmark model ($p = p_0$) are listed in the first row of Table 2 for the purpose of comparison.

[Insert Table 2 about here]

The reason that we choose the model with $p = p_0$ as the benchmark is two fold. First, in the conventional models with constant mortality, health care is not considered and its role in reducing mortality ignored. The comparison between our model and the one with $p = p_0$ captures the general equilibrium effects of introducing health care as an endogenous choice

[11] The combination of $p_0 = 0.2$ and $\overline{p} = 0.6$ implies that the state of medical technology allows for a surviving probability to the retirement age of up to 0.8 in our model.

variable in a growth context. Second, following Ehrlich (2000) to interpret $p = p_0$ as the "natural", or "biological", mortality rate, our comparison then suggests the aggregate impact of deliberate effort in influencing "nature" through health care spending. One immediate result from Table 2 is that the steady-state values of GDP per worker, GDP per capita, and welfare are decidedly higher in our model with health care than their counterparts in the benchmark model for the base case.[12] This conclusion is robust with respect to the state of medical technology and a wide range of other parameter values (see Table 3) as well as alternative model specification (where agents work in both periods). This offers a direct support to the hypothesis that health care is indeed growth and welfare enhancing. Put differently, this result suggests that the empirical studies of growth that do not treat health care as an explicit choice variable tend to either underestimate growth or overestimate the roles of other factors in production. Quantitatively, the table shows that the effects of incorporating health care into the benchmark model are economically significant. For example, depending on the available medical technology, investment in health stock could potentially improve both the steady-state GDP per capita and welfare by as much as about 60% over the benchmark levels.

Table 2 also shows the effects of medical technology. An advance of medical technology, i.e., an increase in $\overline{p}$, leads to increases in all variables listed in Table 2. Consequently, medical advancement is not just a cause for humanitarian concern, it is also of real economic importance. In fact, the economic impact of improving medical technology in our model is quite significant. Pushing the longevity boundary of $\overline{p}$ from 0.1 to 0.8 can bring about 50% increase in per capita GDP and welfare.[13] Naturally, the potency of continuing improvement in medical technology declines as the diminishing returns in both goods production and health production kick in. For instance, an increase of $\overline{p}$ from 0.1 to 0.2 leads to about 13% rise in per capita GDP, while an increase of $\overline{p}$ from 0.7 to 0.8 only leads to roughly 1.4% rise in per capita GDP. Furthermore, the simulation results in Table 2 exhibit a positive association between health expenditure to GDP ratio and medical technology. Such a relationship is rather intuitively: Medical advancement introduces greater incentives to spend on health care by raising the marginal productivity of health production, leading to a higher health expenditure to GDP

[12] Notice that a higher level of GDP *per worker* does not necessarily imply a higher level of GDP *per capita* or welfare. Since a higher steady state k is associated with a greater m, its effect on the level of GDP *per capita* $f(k)/(1 + p(m))$ is, a priori, uncertain. Similarly, it is not obvious that the level of welfare associated with higher k and m is indeed greater.

[13] This result is consistent with the recent work by Murphy and Topel (1999), in which they concluded that the social gains from medical research are derived mainly from prolongation of life expectancy and likely to be enormous.

ratio. Therefore, the observed cross-country pattern in health care expenditure in Table 1 can be potentially, or partially, explained by the different states of medical technology available in countries across different income groups.

Closer examination of Table 1 reveals that the difference in health care spending to GDP ratio between low and middle income countries is relatively small (4.5% and 5.0%, respectively), comparing with that between low/middle and high income countries (8.9% among EMU countries). Matching our simulated health care shares in Table 2 with the data requires a $\overline{p}$ value of roughly 0.15, 0.18, and 0.6 for low income, middle income, and EMU countries, respectively. This would suggest that while the medical technology gap between low and middle income countries is small, EMU/high income countries possess a significant lead in this regard. This implication seems to fit quite well with the casual observation that, while some basic medical technology is readily available all over the world, more advanced and sophisticated medical practices are mostly used in high income countries.

We have also carried out sensitivity analysis of the simulation results discussed above. Varying exogenous parameters within wide ranges of values produced similar results that only differ quantitatively. We are, therefore, reasonably confident that our core analysis and results on the relationship between health care and economic growth in the present paper are quite robust in the qualitative sense. We report some of our sensitivity analysis results in Table 3.[14] The sensitivity results with respect to p_0 reported in Table 3 are perhaps particularly interesting. Other than serving as regular robustness checks, these results also show the quantitative difference between our model with endogenous life expectancy and the conventional model where the changes in longevity are treated as exogenous. These results support our main finding that the exclusion of health care in the analysis will underestimate the steady state income and welfare, and thus health investment is indeed growth promoting.

[Insert Table 3 about here]

We should note that while our model is capable of closely matching the data on health care spending to GDP ratio in different income groups under reasonable parameter values, the simulated survival probabilities in Table 2 are systematically lower than the corresponding

[14] We have also performed simulations with various combinations of the parameters other than those reported in Table 3, and with the inclusion of an explicit discount factor for the second-period utility. In all instances, the simulation results remain qualitatively similar to those in Table 3. In addition, since a definite retirement age may not exist in some countries, we have also checked that our simulation results survive, in fact become stronger, in the extension where agents work in both periods.

probabilities of survival to age 65 observed in Table 1 for similar values of health expenditure share in GDP. One plausible reason of this bias is because we assume that the survival probability is only affected by spending on medical products and services but totally unrelated to consumption activities and/or other external factors. Presumably, how much food, and what food, we consume would heavily influence our health and hence the chances of survival.[15] More importantly, various food and health aid programs by international organizations to a country can have a visible impact on the mortality rate in the country. These effects are likely to be significant for poor countries where adequate nutrition intake is not guaranteed and advanced medical knowledge is lacking. In fact, Preston (1976, 1980) found that various aid programs, both in kind and in medical know-how, had played an important role in the mortality declines in the post-World War II developing countries. Since we did not take into account of these programs in our model, it is not surprising to see that the under-estimation of the survival probability in our simulation is more pronounced for the low/middle income countries.[16]

Another caveat regarding our simulation results is that the order of differences in per-capita GDP observed in Table 2 between countries with different health expenditure shares are noticeably smaller than their counterparts in real life. This may be partly due to the fact that all countries in our model share the same production technology while, in reality, more advanced countries are likely to have a higher total factor productivity measured by A. Overall, the main focus of the present paper is to highlight the potential importance of health care through a simple, partially calibrated model, perhaps at the expense of sacrificing certain degree of realism in other dimensions.

4 Concluding Remarks

In spite of the significance of health care expenditure in many advanced countries, its implication on economic growth has rarely been formally analyzed. In this paper, we have examined the inter-dependence between health care and economic development in a general equilibrium framework. Contrasting to the previous studies, the present paper has endogenized life expectancy through the choice of health care spending. We have shown in our model that health

[15] One justification we can perhaps venture here is that the overall health effect of a consumption bundle may be negligible, as the potential good and bad health effects of different goods we consume offset each other in a wash.

[16] However, transfers of medical resources and technology from abroad can be likened to increases in p_0 in our model. As such, the sensitivity analysis regarding p_0 in Table 3 provides some indication to the impacts of medical aid programs.

care and savings are complements in that they rise and fall together along a development path. Moreover, health care is likely to be a normal good at the aggregate level. Therefore, in the context of economic development, our model is able to replicate several stylized facts observed in the data, namely, (i) countries spend more on health care as they prosper, (ii) rich countries have on average longer life expectancy, and (iii) population aging as measured by the proportion of elderly population is more pronounced in rich countries.

Comparing to an otherwise identical benchmark model with a constant life expectancy, our simulation showed that health care is growth promoting as well as welfare improving: The steady-state GDP per worker, GDP per capita, and welfare in our model are consistently higher than their respective counterparts in the benchmark model. This growth- and welfare-improving impact of health care is particularly interesting because it is achieved despite that health care spending brings a greater dependency ratio (population aging) in the economy. Furthermore, the difference between the two models, for instance in per capita income, can be significant where the medical technology is advanced and effective in extending lives. This suggests that, missing the consideration for health investment, the estimation of the conventional models could be severely biased. Our simulation also revealed that countries with more advanced medical technology converge to steady states with higher per-capita income and higher health care share in GDP.

As a first pass to formally analyze the role of health care in the growth framework, we have chosen indeed a very simple neoclassical model in the present paper. In our model, the positive effects of health care on output and welfare arise from increased savings due to prolonged life expectancy. In reality, there are likely to be other positive effects of health that are not captured here. For example, health improvement may increase work efficiency as well as extend working years of individuals. We expect accounting for these considerations would only reinforce our central thesis in the present paper. On the other hand, our model has also abstracted from some interesting issues that can potentially complicate the current analysis. For example, we have not considered alternative approaches to health care provision such as health insurance or public health sector. A health insurance scheme would require some pay-as-you-go type of inter-generational transfers, which may cause large-than-optimal premiums for the young due to the distorted incentives of the old under the health insurance; while a public health system financed by income tax would introduce inefficiencies due to the distortionary nature of the tax. Extensions in these directions, however, deserve further research.

Appendix

Proof of Proposition 1: Ignoring the time subscript and substituting (9) and (15) into (13), we have

$$p(m)v'\left(\frac{sf'(s)}{p(m)}\right)f'(s) = p'(m)v\left(\frac{sf'(s)}{p(m)}\right).$$

Differentiating both sides with respect to m and denoting $c = \frac{sf'(s)}{p(m)}$, one obtains

$$\begin{aligned} & p'(m)v'(c)f'(s) + p(m)\left[v''(c)f'(s)\left(\frac{f'(s)+sf''(s)}{p(m)}\frac{ds}{dm} - \frac{p'(m)}{p(m)^2}\right) + v'(c)f''(s)\frac{ds}{dm}\right] \\ = \; & p''(m)v(c) + p'(m)v'(c)\left[\frac{f'(s)+sf''(s)}{p(m)}\frac{ds}{dm} - \frac{p'(m)}{p(m)^2}\right]. \end{aligned}$$

Rearranging the above equation yields

$$\begin{aligned} & p'(m)v'(c)f'(s) - v''(c)f'(s)\frac{p'(m)}{p(m)} - p''(m)v(c) + p'(m)v'(c)\frac{p'(m)^2}{p(m)^2} \\ = \; & \left[\left(p'(m)v'(c) - p(m)v''(c)f'(s)\right)\left(\frac{f'(s)+sf''(s)}{p(m)}\right) - v'(c)f''(s)\right]\frac{ds}{dm}. \end{aligned}$$

It is then clear that $\frac{ds}{dm} > 0$ under the assumption (A) and the properties of functions $f(\cdot)$, $v(\cdot)$, and $p(\cdot)$.

Proof of Proposition 2: From (22), (24) and (25), they imply

$$\begin{aligned} \frac{1}{[f(k_t) - k_t f'(k_t) - s(m_t) - m_t]^\gamma} &= p(m_t)^{1+\gamma} s(m_t)^{-\gamma} f'(s(m_t))^{1-\gamma} \\ &= (\alpha A)^{1-\gamma}\, p(m_t)^{1+\gamma} s(m_t)^{-\gamma} s(m_t)^{(\alpha-1)(1-\gamma)} \\ &= (\alpha A)^{1-\gamma}\, p(m_t)^{1+\gamma} s(m_t)^{\alpha(1-\gamma)-1} \\ &= \frac{(\alpha A)^{1-\gamma}}{(1-\gamma)^{1-\alpha(1-\gamma)}} \cdot \frac{p'(m_t)^{1-\alpha(1-\gamma)}}{p(m_t)^{(1-2\alpha)(1-\gamma)}} \end{aligned}$$

Suppose that k_t rises and m_t falls. It is clear that the left hand side of the above equation will decrease. However, since α, $\gamma \in (0, 1)$, the right hand side will increase if $\alpha < \frac{1}{2}$. The contradiction completes the proof.

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Table 1: Data selected from World Development Indicators 2001

	Health expenditure % of GDP[a]	Life expectancy at birth (years)[b]	Survival to age 65 Male[c]	Survival to age 65 Female[c]	Population aged 65 and above[d]
World	5.5	66	65	73	6.7
Low income countries	4.5	59	55	60	4.2
Low/middle countries	4.8	64	62	69	5.5
Middle income countries	5.0	69	68	78	6.6
High income countries	9.7	78	81	91	14.0
EMU countries	8.9	78	80	91	15.9

[a] Average over the period of 1990-1998
[b] For cohort born in 1999 according to the age-specific mortality rate
[c] Percentage of cohort born in 1999 who would survive to age 65 according to the age-specific mortality rate
[d] Percentage of total population in 1999

Table 2: Summary of simulation results

Other parameters: $p_0 = 0.2$, $\alpha = 0.33$, $\gamma = 0.5$, $A = 10$

$\overline{p}$	Health expenditure % of GDP	Survival probability	GDP per worker	GDP per capita	Steady state welfare
Benchmark	0.00	0.20	6.39	5.33	5.31
0.1	3.14	0.24	7.27	5.85	5.65
0.2	5.78	0.32	8.65	6.57	6.21
0.3	7.27	0.39	10.03	7.19	6.75
0.4	8.14	0.48	11.34	7.68	7.24
0.5	8.66	0.56	12.56	8.04	7.67
0.6	8.98	0.65	13.67	8.31	8.05
0.7	9.15	0.73	14.69	8.49	8.38
0.8	9.25	0.82	15.62	8.61	8.66

Table 3: Sensitivity analysis

Other parameters: $p_0 = 0.2$, $\bar{p} = 0.6$, $\gamma = 0.5$, $A = 10$

α	Benchmark Model			Our Model		
	Survival probability	GDP per capita	Steady state welfare	Survival probability	GDP per capita	Steady state welfare
0.25	0.2	6.02	5.74	0.63	7.38	7.60
0.30	0.2	5.62	5.49	0.64	7.90	7.86
0.33	0.2	5.33	5.31	0.65	8.31	8.05
0.35	0.2	5.18	5.21	0.65	8.53	8.15
0.40	0.2	4.69	4.89	0.65	9.28	8.46

Other parameters: $p_0 = 0.2$, $\bar{p} = 0.6$, $\alpha = 0.33$, $A = 10$

γ	Benchmark Model			Our Model		
	Survival probability	GDP per capita	Steady state welfare	Survival probability	GDP per capita	Steady state welfare
0.1	0.2	6.47	6.71	0.61	8.73	9.57
0.3	0.2	5.86	5.59	0.63	8.52	8.37
0.5	0.2	5.33	5.31	0.65	8.31	8.05
0.7	0.2	4.85	6.25	0.67	8.04	9.33
0.9	0.2	4.42	13.78	0.71	7.31	19.90

Other parameters: $p_0 = 0.2$, $\bar{p} = 0.6$, $\alpha = 0.33$, $\gamma = 0.5$

A	Benchmark Model			Our Model		
	Survival probability	GDP per capita	Steady state welfare	Survival probability	GDP per capita	Steady state welfare
1	0.2	0.17	0.94	0.27	0.19	1.03
5	0.2	1.88	3.15	0.54	2.78	4.40
10	0.2	5.33	5.31	0.65	8.31	8.05
15	0.2	9.79	7.19	0.69	15.59	11.30
20	0.2	15.06	8.92	0.71	24.28	14.31

Other parameters: $\bar{p} = 0.6$, $\alpha = 0.33$, $\gamma = 0.5$ $A = 10$

p_0	Benchmark Model			Our Model		
	Survival probability	GDP per capita	Steady state welfare	Survival probability	GDP per capita	Steady state welfare
0.10	0.10	3.49	3.88	0.55	7.93	7.50
0.15	0.15	4.50	4.66	0.60	8.14	7.79
0.20	0.20	5.33	5.31	0.65	8.31	8.05
0.25	0.25	6.01	5.86	0.69	8.45	8.29
0.30	0.30	6.58	6.35	0.74	8.56	8.50

Appendix I

(For reference only, not intended for publication)

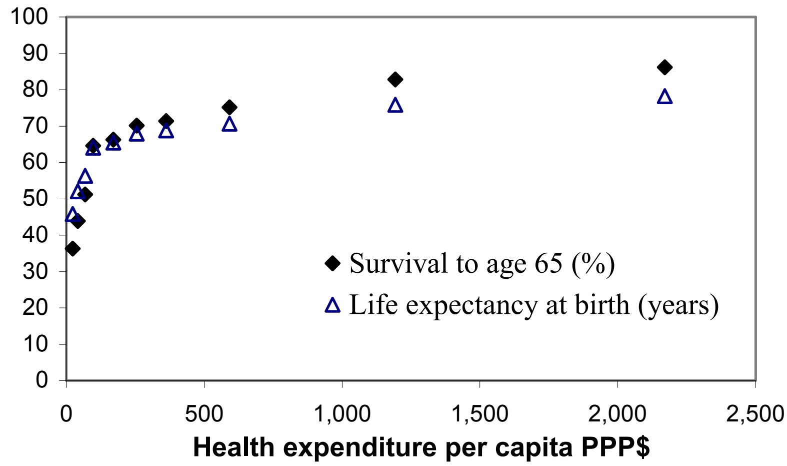
In this appendix, we present some aggregate data to justify the theoretical formulation used in our model of the relationship between health care spending and the survival probability to old age. We extract the data on health expenditure per capita, survival rate to age 65, and life expectancy at birth for 133 countries from World Development Indicators 2001 compiled by the World Bank. To avoid unnecessary noise, we examine the group averages of those variables by dividing the 133 countries equally into ten groups (percentiles) according to their health expenditures per capita in PPP$, with Group 1 containing countries that have the lowest and Group 10 containing countries that have the highest health expenditures per capita. Table A lists the group averages of these variables. The scatter plots in Figure A clearly support our specifications of the function $p(m)$ in the model.

Table A: Mortality indicators and health expenditures

Countries	Health expenditure per capita (PPP$)	Life expectancy at birth (years)	Survival to age 65 (%)* Male	Female	Average
Group 1	24	46	33	39	36
Group 2	42	52	41	46	44
Group 3	68	56	48	54	51
Group 4	98	64	60	69	65
Group 5	170	65	61	72	66
Group 6	256	68	65	75	70
Group 7	362	69	64	79	71
Group 8	592	71	68	82	75
Group 9	1,193	76	78	88	83
Group 10#	2,171	78	82	91	86

* Percentage of newborns who would survive to age 65 according to current age-specific mortality rate
\# Group 10 contains 3 more countries than other groups, in order to exhaust the full sample of countries

Figure A: Mortality indicators and health expenditures



Appendix II

(For reference only, not intended for publication)

The purpose of this appendix is to show that our analysis in the present paper can be readily extended to a model in which individuals work in both periods when young and old. The life time utility for an individual is rewritten as

$$U(c_t^t, c_{t+1}^t) = u(c_t^t) + p(m_t)v(c_{t+1}^t) \tag{A1}$$

where $c_t^t = w_t - s_t - m_t$ and $c_{t+1}^t = w_{t+1} + s_t(1+r_t) + \tau_t$ with $\tau_t = \frac{1-P_t}{P_t} s_t(1+r_t)$. For illustration, we will continue using our parametric model in Section 3 with equations (21), (22), and (23). The first order conditions with respect to s_t and m_t are:

$$\left[\frac{c_{t+1}^t}{c_t^t}\right]^\gamma = p(m_t)(1+r_t) \tag{A2}$$

$$\left[\frac{1}{c_t^t}\right]^\gamma = p'(m_t)\frac{\left(c_{t+1}^t\right)^{1-\gamma}}{1-\gamma}. \tag{A3}$$

Since $w_t = (1-\alpha)Ak_t^\alpha$ and $1 + r_t = \alpha Ak_{t+1}^{\alpha-1}$, it follows that $c_{t+1}^t = \left[(1-\alpha) + \frac{\alpha}{p(m_t)}\right] As_t^\alpha$. Then, making use of the capital market clearing condition

$$k_{t+1} = s_t, \tag{A4}$$

we can solve from (A2) and (A3) that

$$s_t = \frac{\alpha(1-\gamma)}{[\alpha + (1-\alpha)p(m_t)]}\left[\frac{p(m_t)^2}{p'(m_t)}\right]. \tag{A5}$$

It is easy to verify from (A5) that s_t is an increasing function of m_t so that they are, again, complements in equilibrium. After algebraic manipulation, (A3) becomes

$$\frac{1}{[(1-\alpha)Ak_t^\alpha - s_t - m_t]} = \frac{\alpha^{\alpha(1-\gamma)}A^{1-\gamma}}{(1-\gamma)^{1-\alpha(1-\gamma)}} \cdot \frac{[\alpha + (1-\alpha)p(m_t)]^{(1-\alpha)(1-\gamma)}\, p'(m_t)^{1-\alpha(1-\gamma)}}{p(m_t)^{(1-2\alpha)(1-\gamma)}}. \tag{A6}$$

The dynamical system is fully determined by (A4), (A5), and (A6) for any given k_0. We have performed simulations on this system and found that, for example, the results reported in Table 2 are qualitatively similar. In fact, in all instances, the simulated steady-state output per capita and welfare are even higher in the extended model than those in our main model. Intuitively, when agents are working in both periods, the entire population is equally productive. Therefore, the effect that rising life expectancy would raise the proportion of unproductive population is missing, leading to higher output per capita and welfare in the steady state.