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I

A STOCK APPROACH TO THE DEMAND FOR HEALTH

In this chapter, I develop a model to analyze the demand for the commodity good health. The central proposition of the model is that health is a durable commodity. Individuals are said to inherit an initial stock of health that depreciates over time and can be augmented by investment. Death is said to occur when the stock falls below a certain level, and one of the novel features of the model is that individuals "choose" their length of life. I first describe how a given consumer selects the optimal amount of health in any period of his life. I then formalize the equilibrium conditions for health and the other arguments of the utility function and also comment on some general features of the model.

1. THE MODEL

Let the intertemporal utility function of a typical consumer be

$$U = U(\phi_0 H_0, \ldots, \phi_n H_n, Z_0, \ldots, Z_n), \qquad (1\text{-}1)$$

where H_0 is the inherited stock of health, H_i is the stock of health in the ith time period, ϕ_i is the service flow per unit stock, $h_i = \phi_i H_i$ is total consumption of "health services," and Z_i is total consumption of another commodity[1] in the ith period.[2] Note that whereas in the usual intertemporal utility function, the length of life (n) as of the planning date is fixed, here it is an endogenous variable. In particular, death takes place when $H_i = H_{\min}$. Therefore, length of life depends on the quantities of H_i that maximize utility subject to certain production and resource constraints that are now outlined.

By definition, net investment in the stock of health equals gross investment minus depreciation:

$$H_{i+1} - H_i = I_i - \delta_i H_i, \qquad (1\text{-}2)$$

where I_i is gross investment and δ_i is the rate of depreciation during the ith period. The rates of depreciation are assumed to be exogenous, but

[1] The commodity Z_i may be viewed as an aggregate of all commodities besides health that enter the utility function in period i.

[2] For the convenience of the reader, a glossary of symbols follows each chapter.

they may vary with the age of the individual.[3] Consumers produce gross investments in health and the other commodities in the utility function according to a set of household production functions:

$$
\begin{aligned}
I_i &= I_i(M_i, TH_i; E_i) \\
Z_i &= Z_i(X_i, T_i; E_i).
\end{aligned}
\tag{1-3}
$$

In these equations, M_i is medical care, X_i is the goods input in the production of the commodity Z_i, T_i and TH_i are time inputs, and E_i is the stock of human capital.[4] It is assumed that a shift in human capital changes the efficiency of the production process in the nonmarket sector of the economy, just as a shift in technology changes the efficiency of the production process in the market sector. The implications of this treatment of human capital are explored in Chapter II.

It is also assumed that all production functions are homogeneous of degree one in the goods and time inputs. Therefore, the gross investment production can be written as

$$I_i = M_i g(t_i; E_i), \tag{1-4}$$

where $t_i = TH_i/M_i$. It follows that the marginal products of time and medical care in the production of gross investment in health are

$$
\begin{aligned}
\frac{\partial I_i}{\partial TH_i} &= \frac{\partial g}{\partial t_i} = g' \\
\frac{\partial I_i}{\partial M_i} &= g - t_i g'.
\end{aligned}
\tag{1-5}
$$

From the point of view of the individual, both market goods and own time are scarce resources. The goods budget constraint equates the

[3] In a more complicated version of the model, the rate of depreciation might be a negative function of the stock of health. The analysis is considerably simplified by treating this rate as exogenous, and the conclusions reached would tend to hold even if it were endogenous.

[4] In general, medical care is not the only market good in the gross investment function, for inputs such as housing, diet, recreation, cigarette smoking, and alcohol consumption influence one's level of health. Since these inputs also produce other commodities in the utility function, joint production occurs in the household. For an analysis of this phenomenon, see Chapter VI. Until then, medical care is treated as the most important market good in the gross investment function. This treatment is adopted because the other inputs are difficult to measure empirically.

present value of outlays on goods to the present value of earnings income over the life cycle plus initial assets (discounted property income):[5]

$$\sum \frac{P_i M_i + F_i X_i}{(1 + r)^i} = \sum \frac{W_i TW_i}{(1 + r)^i} + A_0. \tag{1-6}$$

Here P_i and F_i are the prices of M_i and X_i, W_i is the wage rate, TW_i is hours of work, A_0 is discounted property income, and r is the interest rate. The time constraint requires that Ω, the total amount of time available in any period, must be exhausted by all possible uses:

$$TW_i + TH_i + T_i + TL_i = \Omega, \tag{1-7}$$

where TL_i is time lost from market and nonmarket activities due to illness or injury.

Equation (1-7) modifies the time budget constraint in Gary S. Becker's time model.[6] If sick time were not added to market and nonmarket time, total time would *not* be exhausted by all possible uses. My model assumes that TL_i is inversely related to the stock of health; that is, $\partial TL_i/\partial H_i < 0$. If Ω were measured in days ($\Omega = 365$ days if a year is the relevant period) and if ϕ_i were defined as the flow of healthy days yielded by a unit of H_i, h_i would equal the total number of healthy days in a given year.[7] Then one could write

$$TL_i = \Omega - h_i. \tag{1-8}$$

It is important to draw a sharp distinction between sick time and the time input in the gross investment function. As an illustration of this difference, the time a consumer allocates to visiting his doctor for periodic checkups is obviously not sick time. More formally, if the rate of depreciation were held constant, an increase in TH_i would increase I_i and H_{i+1} and would reduce TL_{i+1}. Thus, TH_i and TL_{i+1} would be negatively correlated.[8]

By substituting for TW_i from equation (1-7) into equation (1-6), one obtains the single "full wealth" constraint

$$\sum \frac{P_i M_i + F_i X_i + W_i(TH_i + T_i + TL_i)}{(1 + r)^i} = \sum \frac{W_i \Omega}{(1 + r)^i} + A_0 = R. \tag{1-9}$$

[5] Except where indicated, the sums throughout this study are taken from $i = 0$ to n.

[6] See "A Theory of the Allocation of Time," *Economic Journal*, 75, No. 299 (September 1965).

[7] If the stock of health yielded other services besides healthy days, ϕ_i would be a vector of service flows. This study emphasizes the service flow of healthy days because this flow can be measured empirically.

[8] For a discussion of conditions that would produce a positive correlation between TH_i and TL_{i+1}, see Chapter II, Section 2.

According to equation (1-9), full wealth equals initial assets plus the present value of the earnings an individual would obtain if he spent all of his time at work. Part of this wealth is spent on market goods, part of it is spent on nonmarket production time, and part of it is lost due to illness. The equilibrium quantities of H_i and Z_i can now be found by maximizing the utility function given by equation (1-1) subject to the constraints given by equations (1-2), (1-3), and (1-9).[9] Since the inherited stock of health and the rates of depreciation are given, the optimal quantities of gross investment determine the optimal quantities of health capital.

2. EQUILIBRIUM CONDITIONS

First order optimality conditions for gross investment in period $i - 1$ are[10]

$$\frac{\pi_{i-1}}{(1+r)^{i-1}} = \frac{W_i G_i}{(1+r)^i} + \frac{(1-\delta_i)W_{i+1}G_{i+1}}{(1+r)^{i+1}} + \dots + \frac{(1-\delta_i)\dots(1-\delta_{n-1})W_n G_n}{(1+r)^n} + \frac{Uh_i G_i}{\lambda} + \dots + (1-\delta_i)\dots(1-\delta_{n-1})\frac{Uh_n G_n}{\lambda}. \tag{1-10}$$

$$\pi_{i-1} = \frac{P_{i-1}}{g - t_{i-1}g'} = \frac{W_{i-1}}{g'}. \tag{1-11}$$

The new symbols in these equations are Uh_i, the marginal utility of healthy days; λ, the marginal utility of wealth; $G_i = \partial h_i/\partial H_i = -\partial TL/\partial H_i$, the marginal product of the stock of health in the production of healthy days; π_{i-1}, the marginal cost of gross investment in health in period $i - 1$.

Equation (1-10) simply states that the present value of the marginal cost of gross investment in period $i - 1$ must equal the present value

[9] In addition, the constraint is imposed that $H_n \leq H_{min}$.

[10] Note that an increase in gross investment in period $i - 1$ increases the stock of health in all future periods. These increases are equal to $\partial H_i/\partial I_{i-1} = 1, \partial H_{i+1}/\partial I_{i-1} = (1 - \delta_i), \dots, \partial H_n/\partial I_{i-1} = (1 - \delta_i)(1 - \delta_{i+1})\dots(1 - \delta_{n-1})$. Note also that if Z_i were nondurable, its first order conditions would be

$$\frac{U_i}{\lambda} = \frac{q_i}{(1+r)^i}, \qquad q_i = \frac{F_i}{\partial Z_i/\partial X_i} = \frac{W_i}{\partial Z_i/\partial T_i}.$$

For a derivation of equation (1-10), see Appendix A, Section 1.

of marginal benefits. Discounted marginal benefits at age i equal $G_i[W_i(1 + r)^{-i} + Uh_i\lambda^{-1}]$, where G_i is the marginal product of health capital—the increase in the number of healthy days caused by a one unit increase in the stock of health. Two monetary magnitudes are necessary to convert this marginal product into value terms because consumers desire health for two reasons. The discounted wage rate measures the monetary value of a one unit increase in the total amount of time available for market and nonmarket activities, and the term Uh_i/λ measures the discounted monetary equivalent of the increase in utility due to a one unit increase in healthy time. Thus, the sum of these two terms measures the discounted marginal value to consumers of the output produced by health capital.

While equation (1-10) determines the optimal amount of gross investment in period $i - 1$, equation (1-11) shows the condition for minimizing the cost of producing a given quantity of gross investment. Total cost is minimized when the change in gross investment from spending an additional dollar on medical care equals the change in gross investment from spending an additional dollar on time. Since the gross investment production function is homogeneous of degree one and since the prices of medical care and own time are independent of the level of these inputs, average cost is constant and equal to marginal cost.

To examine the forces that affect the demand for health and gross investment, it is useful to convert equation (1-10) into a slightly different form. If gross investment in period i is positive, then:

$$\frac{\pi_i}{(1 + r)^i} = \frac{W_{i+1}G_{i+1}}{(1 + r)^{i+1}} + \frac{(1 - \delta_{i+1})W_{i+2}G_{i+2}}{(1 + r)^{i+2}} + \dots + \frac{(1 - \delta_{i+1})\dots(1 - \delta_{n-1})W_nG_n}{(1 + r)^n} + \frac{Uh_{i+1}}{\lambda}G_{i+1} + \dots + (1 - \delta_{i+1})\dots(1 - \delta_{n-1})\frac{Uh_n}{\lambda}G_n. \quad (1\text{-}12)$$

From (1-10) and (1-12),

$$\frac{\pi_{i-1}}{(1 + r)^{i-1}} = \frac{W_iG_i}{(1 + r)^i} + \frac{Uh_i}{\lambda}G_i + \frac{(1 - \delta_i)\pi_i}{(1 + r)^i}.$$

Therefore,

$$G_i[W_i + (Uh_i/\lambda)(1 + r)^i] = \pi_{i-1}(r - \tilde{\pi}_{i-1} + \delta_i), \quad (1\text{-}13)$$

where $\tilde{\pi}_{i-1}$ is the percentage rate of change in marginal cost between period $i - 1$ and period i.[11] Equation (1-13) implies that the undiscounted value of the marginal product of the optimal stock of health capital at any moment in time must equal the supply price of capital, $\pi_{i-1}(r - \tilde{\pi}_{i-1} + \delta_i)$. The latter contains interest, depreciation, and capital gains components and may be interpreted as the rental price or user cost of health capital.

Condition (1-13) fully determines the demand for capital goods that can be bought and sold in a perfect market. In such a market, if firms or households acquire one unit of stock in period $i - 1$ at price π_{i-1}, they can sell $(1 - \delta_i)$ units at price π_i at the end of period i. Consequently, $\pi_{i-1}(r - \tilde{\pi}_{i-1} + \delta_i)$ measures the cost of holding one unit of capital for one period. The transaction just described allows individuals to raise their capital in period *i alone* by one unit and is clearly feasible for stocks like automobiles, houses, refrigerators, and producer durables. It suggests that one can define a set of single period flow equilibria for stocks that last for many periods.

In my model, the stock of health capital cannot be sold in the capital market, just as the stock of knowledge cannot be sold. This means that gross investment must be nonnegative. Although sales of health capital are ruled out, provided gross investment is positive, there exists a user cost of capital that in equilibrium must equal the value of the marginal product of the stock.[12] An intuitive interpretation of this result is that exchanges over time in the stock of health by an individual substitute for exchanges in the capital market. Suppose a consumer desires to increase his stock of health by one unit in period i. Then he must increase gross investment in period $i - 1$ by one unit. If he simultaneously reduces gross investment in period i by $(1 - \delta_i)$ units, then he has engaged in a transaction that raises H_i, and H_i *alone*, by one unit. Put differently, he has essentially rented one unit of capital from himself for one period. The magnitude of the reduction in I_i is smaller the greater the rate of depreciation, and its dollar value is larger the greater the rate of increase in marginal cost over time. Thus, the depreciation and capital gains components are as relevant to the user cost of health as they are to the user cost of any other durable. Of course, the interest component of user cost is easy to interpret, for if one desires to increase his stock of health rather

[11] Equation (1-13) assumes $\delta_i\tilde{\pi}_{i-1} \simeq 0$.

[12] For a similar conclusion, see Kenneth J. Arrow, "Optimal Capital Policy with Irreversible Investment," in J. N. Wolfe (ed.), *Value, Capital and Growth: Papers in Honour of Sir John Hicks*, Edinburgh, 1968.

than his stock of some other asset by one unit in a given period, $r\pi_{i-1}$ measures the interest payment he foregoes.[13]

A slightly different form of equation (1-13) emerges if both sides are divided by the marginal cost of gross investment:

$$\gamma_i + a_i = r - \tilde{\pi}_{i-1} + \delta_i. \tag{1-13'}$$

Here $\gamma_i = W_i G_i / \pi_{i-1}$ is the marginal monetary rate of return to an investment in health and $a_i = [(Uh_i/\lambda)(1 + r)^i G_i]/\pi_{i-1}$ is the psychic rate of return. In equilibrium, the total rate of return to an investment in health must equal the user cost of health capital in terms of the price of gross investment. The latter variable is defined as the sum of the real-own rate of interest and the rate of depreciation.

In Chapters II and III, equation (1-13′) is used to trace out the lifetime path of health and gross investment, to explore the effects of variations in depreciation rates, and to examine the impact of changes in the marginal cost of gross investment. Before turning our attention to these matters, let us consider the following general properties of the model. It should be realized that equation (1-13′) breaks down whenever desired gross investment equals zero. In this situation, the present value of the marginal cost of gross investment would exceed the present value of marginal benefits for all positive quantities of gross investment, and equations (1-10) and (1-12) would be replaced by inequalities.[14] The discussion in the remainder of this study rules out zero gross investment by assumption, but the conclusions reached would have to be modified if this were not the case.

It should also be realized that since there are constant returns to scale in the production of gross investment and since input prices are given, the marginal cost of gross investment and its percentage rate of change over time are exogenous variables. Put differently, these two variables are independent of the rate of investment and the stock of health. This implies that consumers reach their desired stock of capital immediately. It also implies that the stock rather than gross investment is the basic decision variable in the model. By this I mean that consumers respond to changes in the cost of capital by altering the marginal product

[13] In a continuous time model, the user cost of health capital can be derived in one step. If continuous time is employed, the term $\delta_i \tilde{\pi}_{i-1}$ does not appear in the user cost formula. The right-hand side of (1-13) becomes $\pi_i(r - \tilde{\pi}_i + \delta_i)$, where $\tilde{\pi}_i$ is the instantaneous percentage rate of change of marginal cost at age i. For a proof, see Appendix A, Section 2.

[14] Formally, $\gamma_i + a_i \leq r - \tilde{\pi}_{i-1} + \delta_i$, if $I_{i-1} = I_i = 0$.

of health capital and not the marginal cost of gross investment.[15] Therefore, even though equation (1-13′) is not independent of equations (1-10) and (1-12), it can be used to determine the optimal path of health capital and by implication the optimal path of gross investment.[16]

It is clear that the number of sick days and the number of healthy days are complements; their sum equals the constant length of the period. From equation (1-8) the marginal utility of sick time is $-Uh_i$. Thus, by putting healthy days in the utility function, one implicitly assumes that sick days yield *disutility*. If healthy days did not enter the utility function directly, the monetary rate of return would equal the cost of health capital, and health would be solely an investment commodity.[17]

The monetary returns to an investment in health differ from the returns to investments in education, on-the-job training, and other forms of human capital since the latter investments raise wage rates.[18] Of course, the amount of health capital might influence the wage rate, but it necessarily influences the time lost from all activities due to illness or injury. To emphasize the novelty of my approach, I assume that health is not a determinant of the wage rate. Put differently, a person's stock of knowledge affects his market and nonmarket productivity, while his stock of health determines the total amount of time he can spend producing money earnings and commodities.[19] Since both market and nonmarket time are relevant, even individuals who are not in the labor force have an incentive to invest in their health. For such individuals, the marginal product of health capital would be converted into a dollar equivalent by multiplying by the monetary value of the marginal utility of time.

I have been reluctant to label health either pure consumption ($\gamma_i = 0$) or pure investment ($Uh_i = 0$) because many observers believe

[15] In Chapter II, it is shown that if the marginal disutility of sick time equals zero, the determination of the equilibrium stock of capital in period i requires diminishing marginal productivity of capital. For a model in which gross investment is the basic decision variable, see Yoram Ben-Porath, "The Production of Human Capital and the Life Cycle of Earnings," *Journal of Political Economy*, 75, No. 4 (August 1967). Ben-Porath assumes that the marginal product of the stock of knowledge is constant, but the marginal cost of producing gross additions to the stock is positively related to the rate of gross investment.

[16] This statement is subject to the modification that the optimal path of capital must always imply nonnegative gross investment.

[17] To avoid confusion, a note on terminology is in order. If health were entirely an *investment commodity*, it would yield monetary, but not utility, returns. Regardless of whether health is investment, consumption, or a mixture of the two, one can speak of a *gross investment function* since the commodity in question is a durable.

[18] This difference is emphasized by Selma J. Mushkin in "Health as an Investment," *Journal of Political Economy*, 70, No. 5, Part 2 (October 1962), pp. 132–133.

[19] Hence, E_i, the stock of knowledge or human capital, does *not* include health capital.

the demand for it has both investment and consumption aspects.[20] But to simplify the theoretical analysis, Chapter II offers a pure investment interpretation of a certain set of phenomena, while Chapter III offers a pure consumption interpretation of the same set. In both frameworks, the assumption of constant marginal cost guarantees instantaneous adjustments to variables that shift the demand for health in a once and for all fashion. Therefore, there would be no net investment or disinvestment over the life cycle of an individual unless his demand for health were a function of time.

3. GLOSSARY

n	Total length of life
i	Age
H_0	Inherited stock of health
H_i	Stock of health in period i
H_{min}	Death stock
ϕ_i	Service flow per unit stock or number of healthy days per unit stock
h_i	Total number of healthy days in period i
Z_i	Consumption of an aggregate commodity in period i
I_i	Gross investment in health
δ_i	Rate of depreciation
M_i	Medical care
TH_i	Time input in gross investment function
X_i	Goods input in the production of Z_i
T_i	Time input in the production of Z_i
E_i	Stock of human capital
$g - t_i g'$	Marginal product of medical care in the gross investment production function
g'	Marginal product of time
P_i	Price of medical care
F_i	Price of X_i
W_i	Wage rate
A_0	Initial assets
r	Rate of interest

[20] See, for example, Mushkin, *op. cit.*, p. 131; and Victor R. Fuchs, "The Contribution of Health Services to the American Economy," *Milbank Memorial Fund Quarterly*, 44, No. 4, Part 2 (October 1966), p. 86, and reprinted as Chapter 1 in *Essays in the Economics of Health and Medical Care*, New York, NBER, 1972.

TW_i	Hours of work
TL_i	Sick time
Ω	Constant length of the period
R	Full wealth
G_i	Marginal product of health capital
Uh_i	Marginal utility of healthy days
λ	Marginal utility of wealth
π_i	Marginal cost of gross investment in health
$\tilde{\pi}_i$	Percentage rate of change in marginal cost
q_i	Marginal cost of Z_i
γ_i	Monetary rate of return on an investment in health or marginal efficiency of health capital
a_i	Psychic rate of return on an investment in health