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VI

JOINT PRODUCTION AND THE MORTALITY DATA

The empirical results in Chapter V suggest that the income elasticity of healthy days is negative. In this chapter, I offer a theoretical explanation of the negative income effect and assess whether it is present when ill health is measured by the mortality rate. In the first section, I trace the apparent inferiority of health to the existence of "joint production" in the nonmarket sector of the economy. I show that even if the "pure" income effect is positive, as the consumption model predicts, or zero, as the investment model predicts, the observed correlation between health and income might be negative. Using states of the United States as the basic units of observation, the second section offers a direct test of the joint production hypothesis. It also quantifies the relationships between the mortality rate and the principal independent variables utilized in Chapter V. Compared to health status, work-loss days, or restricted-activity days, the mortality rate is a rather extreme indicator of ill health. The death rate is, however, a more objective index than the other three. Consequently, the empirical results obtained with it are presented primarily as a *check* against those obtained with the other measures.

1. THE THEORY OF JOINT PRODUCTION

The formulation of the investment and consumption models assumed that medical care and own time were the only inputs in the gross investment production function. In reality, this function contains a vector of additional market goods that affects the quantity of gross investment produced. The variables in this vector include diet, exercise, recreation, housing, cigarettes, liquor, and rich food. Presumably, the last three goods have *negative* marginal products in the investment production function. These goods are purchased by consumers because they are also inputs into the production of other commodities, such as "smoking pleasure," that yield positive utility. Similarly, beneficial inputs like housing services produce both health and shelter Since a given input can enter more than one production function, joint production occurs in the household.

To incorporate joint production into the analysis, let the set of household production functions be[1]

$$\begin{aligned} I &= I(M, X_1, X_2) \\ Z_1 &= Z_1(X_1) \\ Z_2 &= Z_2(X_2) \\ Z_j &= Z_j(X_j) \qquad j = 3, \ldots, m \end{aligned} \tag{6-1}$$

The input X_1 is a market good that increases gross investment, and the input X_2 is a good that reduces it.[2] Hence, $\partial I/\partial X_1 > 0$ and $\partial I/\partial X_2 < 0$. Note that the type of joint production considered here arises only if X_1 or X_2 *cannot* be divided into two components, one used entirely to produce Z_1 or Z_2 and the other used together with M to produce I.[3] Note also that instead of putting X_1 and X_2 in the gross investment function, one could let them affect the rate of depreciation on the stock of health. This approach has not been taken because a general model of joint production, one that is applicable to durable and nondurable household commodities, is desired.

Even though X_1 and X_2 are inputs in the gross investment production function, the marginal or average cost of gross investment does not directly depend on these two goods or their prices. This follows because when the utility function is maximized with respect to health capital or gross investment, Z_1 and Z_2 (and hence X_1 and X_2) must be held constant.[4] It is true, however, that, with M constant, an increase in X_1 or X_2 will

[1] Equation (6-1) decomposes the aggregate commodity Z into m individual commodities. For simplicity, time inputs and the stock of human capital are omitted from the production functions. The general conclusions reached in this section would not be altered if these variables were included in the analysis.

[2] In other words, market goods that improve health are aggregated into a composite input, X_1, and goods that damage health are aggregated into another composite input, X_2.

[3] Mathematically, the joint production problem discussed in the text does not arise if

$$\begin{aligned} I &= I(M, X_{11}, X_{21}) \\ Z_1 &= Z_1(X_{12}) \\ Z_2 &= Z_2(X_{22}), \end{aligned}$$

where $X_1 = X_{11} + X_{12}$ and $X_2 = X_{21} + X_{22}$.

[4] The above principle is valid even if health does not enter the utility function. Since health influences the full wealth budget constraint, a Lagrangian function must be *partially* differentiated with respect to H, Z_1, and Z_2. See Appendix A, equation (A-1), for this Lagrangian function.

alter the marginal product of medical care and the marginal cost of gross investment.

The relationship between X_1 or X_2 and marginal cost is now examined, and it is shown how these relationships can generate a correlation between income and marginal cost. Instead of developing the theory of joint production in detail, a specific production function is utilized:[5]

$$\ln I = \ln M + \alpha'(\ln X_1 - \ln X_2), \tag{6-2}$$

where α' is the elasticity of gross investment with respect to X_1. This production function is homogenous of degree one in medical care[6] and in all three inputs taken together. It also implies that the absolute value of the negative elasticity of I with respect to X_2 equals the elasticity of I with respect to X_1. Equation (6-2) is consistent with a common assumption in economics: If all relevant inputs are considered, then a production function will exhibit constant returns to scale.

From eqnation (6-2), the natural logarithm of the marginal product of medical care is

$$\ln \frac{\partial I}{\partial M} = \alpha'(\ln X_1 - \ln X_2), \tag{6-3}$$

and the natural logarithm of the marginal cost of gross investment is

$$\ln \pi = \ln P - \ln \frac{\partial I}{\partial M} = \ln P + \alpha'(\ln X_2 - \ln X_1). \tag{6-4}$$

These equations suggest that with M and Z_2 constant, an increase in X_1 will increase the marginal product of medical care and reduce the marginal cost of gross investment. On the other hand, an increase in X_2 will reduce the marginal product of medical care and increase the marginal cost of gross investment. Hence, in the terminology of the literature on production functions, X_1 and M are complements, while X_2 and M are substitutes. The equations also show that the marginal product of medical care and the marginal cost of gross investment depend only on the ratio of X_2 to X_1. In particular, this ratio is negatively correlated with the former variable and positively correlated with the latter.

[5] For a general development of the model, see Michael Grossman, "The Economics of Joint Production in the Household," University of Chicago, Center for Mathematical Studies in Business and Economics, mimeographed, 1971.

[6] If M were viewed as a composite input representing both medical care and own time, equation (6-2) would be consistent with diminishing marginal productivity of medical care.

Suppose income increases, with the prices of market goods and own time, the interest rate, the rate of depreciation on the stock of health, and the efficiency of nonmarket production all held fixed. Under these conditions, will the shadow price of health remain constant? To answer this question, differentiate equation (6-4) with respect to the natural logarithm of income:

$$\eta_\pi = \alpha'(\eta_2 - \eta_1). \tag{6-5}$$

In this equation, η_π is the income elasticity of marginal cost, η_2 is the income elasticity of X_2 or Z_2, and η_1 is the income elasticity of X_1 or Z_1. The equation reveals that marginal cost is independent of income only if Z_1 and Z_2 have the same income elasticities. In general, $\eta_\pi \gtreqless 0$ as $\eta_2 \gtreqless \eta_1$. This follows because the correlation between X_2/X_1 and income depends on the magnitude of η_2 compared to η_1. Given $\eta_2 > \eta_1$, this ratio would rise with income, which would lower the marginal product of medical care and raise marginal cost. The reverse would occur if $\eta_1 > \eta_2$.

Provided $\eta_1 \neq \eta_2$, health would have a nonzero income elasticity even if it were solely an investment commodity. That is, an increase in income would change the marginal cost of gross investment, shift the MEC schedule, and alter the demand for health. In the investment model, the income elasticity of health would be given by[7]

$$\eta_H = \varepsilon\alpha'(\eta_1 - \eta_2), \tag{6-6}$$

and it is clear that $\eta_H < 0$ if $\eta_2 > \eta_1$.[8] Thus, the observed negative income elasticity of healthy days can be explained without resorting to the argument that health is an inferior commodity. Instead, one interpretation of this finding is that the detrimental inputs in the gross investment production function have higher income elasticities than the beneficial inputs. In fact, existing consumer budget studies indicate that alcohol consumption is very income elastic ($\eta = 1.6$), although cigarette smoking is not ($\eta = .6$).[9] The income elasticity of total food consumption

[7] Since $\ln(r + \delta) = \ln W + \ln G - \ln \pi$, $\eta_H = \varepsilon\eta_\pi$. Substitution of equation (6-5) for η_π yields equation (6-6).

[8] In the pure consumption model, health might have a negative income elasticity if $\eta_2 > \eta_1$, but this is not a sufficient condition. Instead, the substitution effect introduced by joint production would have to outweigh the positive income effect that would be observed in its absence. For an elaboration of this argument, see Grossman, "The Economics of Joint Production."

[9] For one set of estimates of income elasticities for items that exhaust total consumption, see Robert T. Michael, *The Effect of Education on Efficiency in Consumption*, New York, NBER, Occasional Paper 116, 1972.

is fairly small ($\eta = .6$), but rich and caloric varieties of food might have large elasticities. In addition, other market goods that as yet have not been identified might have large income elasticities and harmful effects on health.

If the consumption of X_2 were more responsive to changes in income than the consumption of X_1, health would be negatively correlated with income in the investment model. This does not mean that medical care would also have a negative income elasticity. In particular, wealthier persons might have an incentive to offset *part* of the reduction in health caused by an increase in X_2/X_1 by increasing their medical outlays. One easily shows that the income elasticity of medical care would equal[10]

$$\eta_M = \alpha'(\eta_1 - \eta_2)(\varepsilon - 1). \tag{6-7}$$

Assume $\eta_2 > \eta_1$ so that η_H is negative. Then according to equation (6-7), η_M would be positive if the elasticity of the MEC schedule were less than unity. Given this condition, wealthier persons would simultaneously reduce their demand for health but increase their demand for medical care. These are precisely the relationships that were observed in Chapter V.

One final comment on the effects of joint production is in order. The law of the downward sloping demand curve, the most fundamental law in economics, indicates that the quantity of X_2 demanded would be negatively correlated with its price. So an increase in $P2$, the price of X_2, would raise the marginal product of medical care, lower the marginal cost of gross investment, and increase the demand for health. A formula for the elasticity of health with respect to $P2$ is

$$e_{P2} = -\varepsilon\alpha' e_2, \tag{6-8}$$

where e_2 is the price elasticity of demand for X_2 (defined to be positive).[11] Since e_{P2} exceeds zero, health and X_2 are substitutes. On the other hand, an increase in $P1$, the price of X_1, would lower the marginal product of medical care, raise marginal cost, and reduce the demand for health. Consequently, health and X_1 are complements. This formulation suggests a direct test of the joint production hypothesis. If $P1$ and $P2$ entered the

[10] Since $\ln M = \ln I + \alpha'(\ln X_2 - \ln X_1)$ and since $\eta_I = \eta_H$, $\eta_M = \eta_H + \alpha'(\eta_2 - \eta_1)$. Substitution of equation (6-6) for η_H yields equation (6-7).

[11] From the definition of the monetary rate of return on an investment in health, $e_{P2} = -\varepsilon(d \ln \pi/d \ln P2)$. Differentiating equation (6-4) with respect to $\ln P2$, one gets $d \ln \pi/d \ln P2 = -\alpha' e_2$. Substituting the last equation into the expression for e_{P2}, one has equation (6-8). This derivation assumes that the demand for X_1 is independent of the price of X_2.

set of exogenous variables in the health demand curve, then the regression coefficient of $P1$ should be negative, and the coefficient of $P2$ should be positive.

2. THE MORTALITY DATA

This section presents estimates of health demand functions in which ill health is measured by the mortality rate. The basic units of observation are 48 of the 50 states of the United States (Alaska and Hawaii are excluded) for the year 1960. The transition from individual data to data grouped by states is made by postulating homoscedasticity at the individual level. This implies that each observation should be weighted by the square root of the state's population.[12]

The specific mortality variable employed is the crude death rate of the white population, d. This variable essentially measures the fraction of the people in a given state who had no healthy days or 365 sick days in 1960.[13] Since d is analogous to TL and since the investment model suggests $-\ln TL$ should be the dependent variable in the health flow demand curve, the dependent variable in the mortality regressions is $-\ln d$. To take account of variations in the crude death rate due to variations in age and sex population distributions across states, an expected death rate, $\bar{d}$, enters the regressions as one of the independent variables. This variable was computed by applying U.S. age-sex specific death rates of whites to age-sex population distributions of whites in each state. It is described in more detail in Appendix F.

The other exogenous variables include family income, the wage rate, education, average hourly earnings of paramedical personnel (all members of the health industry excluding doctors) adjusted for quality (PN), and the price of cigarettes per pack (PC).[14] Hourly earnings of paramedical personnel are employed as an index of the price of medical care. In principle, this index should also take account of variations in the price of physicians' services across states. Unfortunately, data on physicians'

[12] See E. Malinvaud, *Statistical Methods of Econometrics*, Amsterdam, 1966, pp. 242–246. The coefficients obtained from unweighted regressions (not shown) are fairly similar to the weighted regression coefficients presented in this section.

[13] This assumes that all deaths occurred at the beginning of the year. If this were not the case, the above interpretation of d would still be valid provided a long period of illness preceded death.

[14] The regressions in the text exclude family size from the set of exogenous variables. Wnen it was included, its own regression coefficient was extremely small, and the other coefficients were not affected.

income for the year 1960 are not readily available. The price of cigarettes measures the price of one of the detrimental inputs in the gross investment production function. The prices of other inputs in the production function are assumed to be constant. This assumption is advanced because these inputs are difficult to identify and because information on their prices is virtually nonexistent.[15] Detailed definitions of all the exogenous variables and the data sources from which they were taken are discussed in Appendix F.

Table 11 shows the mortality demand curves. Since family income and the wage rate are very highly correlated ($r = .946$), the table contains three regressions. The first one includes both these variables, the second omits the wage, and the third omits income. The $\bar{R}^2$ are large in all three regressions because the expected death rate is one of the independent variables. Preliminary regressions with $-\ln(d/\hat{d})$ as the dependent variable yielded $\bar{R}^2$ equal to .6.[16] The regression coefficients and t ratios of the other independent variables were almost identical, however, to those in Table 11.

TABLE 11
Demand for Health in States of the United States, 1960

Regression Number	$\ln Y$	$\ln W$	E	$-\ln \hat{d}$	$\ln PN$	$\ln PC$	$\bar{R}^2$
1	−.496	.332	.054	.842	−.330	.019	.913
	(−4.48)	(2.83)	(6.51)	(15.32)	(−2.71)	(.25)	
2	−.226		.056	.916	−.252	−.008	.898
	(−3.71)		(6.25)	(15.45)	(−1.96)	(−.10)	
3		−.120	.057	.867	−.422	−.038	.873
		(−1.66)	(5.68)	(13.55)	(−2.92)	(−.43)	

NOTE: In all regressions, the dependent variable is $-\ln d$.

Regression 1 reveals that income, the wage, and education have the *same effects* on mortality as they do on sick time. Income is positively correlated with these two measures of ill health, the wage is negatively

[15] I computed an implicit price of liquor by dividing expenditures by a quantity index (total absolute alcohol content in gallons of sales per person of drinking age). When the quantity index was regressed on income and price, the estimated price elasticity was zero. For this reason, the price variable was excluded from the mortality regressions.

[16] This form assumes that the elasticity of d with respect to $\hat{d}$ equals one.

correlated with them, and so is education.[17] Moreover, the magnitudes of the coefficients in regression 1 are fairly similar to the magnitudes of the corresponding coefficients in the NORC health flow demand curves. For example, if all other variables were held constant, a one-year increase in the level of formal schooling would reduce the white mortality and sick time rates by approximately 5.4 and 4.6 percent. To cite another illustration, the wage elasticities of $-d$, $-WLD1$, and $-RAD$ equal .332, .471, and .341, respectively.[18]

Not all the empirical results of the mortality analysis are in complete agreement with those of the NORC analysis. The negative income elasticity of $-d$ is approximately twice as large as the income elasticity of sick time ($-.496$ compared with $-.177$ when $-TL = -WLD1$ or $-.226$ when $-TL = -RAD$). Hence, although the NORC wage elasticity of health is larger than the absolute value of the income elasticity, the reverse is true in the mortality demand curve. In addition, regressions 2 and 3 show that if either income or the wage is excluded from the set of independent variables, the remaining variable has a negative elasticity. On the other hand, the gross wage and income elasticities of health are positive in the NORC sample.

In one sense, the finding that the death rate is positively related to income and negatively related to the wage rate is due to the extremely high correlation between $\ln Y$ and $\ln W$ ($r = .946$). When a dependent variable is regressed on two such highly correlated variables, it can be easily proven that their regression coefficients are bound to have opposite signs.[19] In another sense, however, this finding is important from a theoretical point of view. Suppose one did not have a theory to explain

[17] Using the same basic data, Victor R. Fuchs and Richard D. Auster, Irving Leveson, and Deborah Sarachek found a positive correlation between income and mortality and a negative correlation between education and mortality. See Fuchs, "Some Economic Aspects of Mortality in the United States," New York, NBER, mimeographed, 1965; and Auster, Leveson, and Sarachek, "The Production of Health, an Exploratory Study," *Journal of Human Resources*, 4, No. 4 (Fall 1969), and reprinted as Chapter 8 in Victor R. Fuchs (ed.), *Essays in the Economics of Health and Medical Care*, New York, NBER, 1972. The main difference between my analysis and that of Fuchs and Auster, Leveson, and Sarachek is that I emphasize the demand curve for health, while they emphasize the production function.

[18] The wage elasticities of $-WLD1$ and $-RAD$, as well as the income elasticities cited in the next paragraph, are taken from Table 6.

[19] See Reuben Gronau, "The Effect of Traveling Time on the Demand for Passenger Airline Transportation," unpublished Ph.D. dissertation, Columbia University, Chapter 6. In general, if the two variables in question have positive simple correlation coefficients with the dependent variable, then the one with the larger correlation would exhibit a positive coefficient in the multiple regression.

the forces influencing the demand for health. Then he could not predict whether income or the wage would be more likely to have a negative effect on mortality. Since the value of the marginal product of health capital is more closely related to the wage than to income, the investment model would predict a negative wage elasticity of the death rate. This is precisely what is observed empirically.[20]

The first regression in Table 11 indicates that the two price variables have the "correct signs" in the mortality demand curve. An increase in the price of paramedical personnel, which represents an increase in the marginal cost of gross investment, reduces the quantity of health demanded. The computed elasticity of $-d$ with respect to PN is $-.330$. In accordance with the notion that the shadow price of health is negatively correlated with the price of cigarettes, this price has a positive health elasticity. This elasticity is small ($e_{P2} = .019$), and unfortunately, it is not statistically significant. Moreover, it becomes negative when either income or the wage is excluded from the regressions. Since $e_{P2} = \varepsilon\alpha' e_2$ and since $\varepsilon = .5$, e_{P2} would be small if the demand for cigarettes were price-inelastic.[21] Based on the state data, e_2 equals .4, which implies that α' equals .1. That is, a 1 percent increase in cigarette smoking would reduce the marginal product of medical care by one-tenth of 1 percent. This estimate of α' coincides with a direct calculation of the elasticity of the mortality rate with respect to cigarette consumption made by Auster, Leveson, and Sarachek.[22]

In summary, the remarkable qualitative and quantitative agreement between the mortality and sick time regression results should strengthen our confidence in the health measures utilized in Chapter V and in the way these measures have been interpreted. Even though the mortality rate is a more objective measure of ill health than sick time, variations in income, education, and the wage rate have similar effects on these two indexes. Perhaps the most striking finding in this study is that health has a negative income elasticity. One explanation of this result is that the income elasticities of the detrimental inputs in the health production

[20] Morris Silver should again be credited with stressing the importance of the wage variable in the health demand curve. He argues that health is a time-intensive *consumption* commodity and that an increase in W should increase the death rate. See "An Econometric Analysis of Spatial Variations in Mortality by Race and Sex," in Fuchs (ed.), *op. cit.*, Chap. 9.

[21] In addition, the health elasticity of the price of cigarettes might be small because knowledge about the detrimental effects of smoking was not widespread prior to the issuance of the Surgeon General's report on health and smoking in 1964.

[22] See "The Production of Health," Tables 3 and 4.

function exceed those of the beneficial inputs, although the evidence in support of this view is by no means overwhelming. Future research should attempt to identify the harmful inputs and assess how sensitive their consumption is to changes in the level of income.

3. GLOSSARY

X_1	A market good with a positive marginal product in the gross investment production function
X_2	A market good with a negative marginal product in the gross investment production function
α'	Elasticity of gross investment with respect to X_1
$-\alpha'$	Elasticity of gross investment with respect to X_2
η_π	Income elasticity of marginal cost
η_1	Income elasticity of X_1
η_2	Income elasticity of X_2
η_H	Income elasticity of health
η_M	Income elasticity of medical care
$P1$	Price of X_1
$P2$	Price of X_2
e_2	Price elasticity of X_2
e_{P2}	Health elasticity of P_2
d	Crude death rate, states of the United States
$\hat{d}$	Expected death rate
PN	Price of paramedical personnel
PC	Price of cigarettes