COMPARTMENT MODEL METHODS IN ESTIMATING CANCER COSTS

H. Dennis Tolley, Battelle, Pacific Northwest Laboratories,
Kenneth G. Manton, Eric Stallard, Duke University

ABSTRACT

Efficient public planning and policy-making in the health care sector frequently requires the availability of good estimates of current and future costs of disease. Although experience data are maintained and utilized by the insurance industry, these data to not permit extrapolation beyond the select population from which they are gathered. This paper proposes using a stochastic compartment model to integrate morbidity and mortality data for certain chronic diseases into a comprehensive and biomedically realistic representation of the disease process over age in a population group identified by race, sex, geographic region or other demographic characteristics. Such a model permits estimation of the number of persons requiring treatment for a specific disease both currently, and by projection, in the future. Further, manipulation of biomedically meaningful parameters of the model permits assessment of costs under alternate assumptions about the improvement in medical technology. The methodology is illustrated using U.S. white male lung cancer morbidity and mortality data from the period 1950 to 1977.

INTRODUCTION

In this paper, we propose the use of stochastic compartment model methods for estimating both the current direct and indirect costs of specific cancers and for forecasting future direct and indirect costs. The purpose of the estimates in this paper is assumed to be primarily for public planning and policy-making so that we must consider the health risks of the general population rather than simply of a select population such as insured cohort. Consideration of the general population entails additional problems in that there is no experience data for the general population. Similar problems arise with select populations when coverage is extended to new population groups (e.g., to older age groups) and when projecting future costs. In either case, more accurate cost projections can be developed if a) standard actuarial methodology can be adapted to compartment model predicting primary health risks, b) the compartment model can utilize the wide range of health survey data on the general population to (indirectly) reflect the health risks of interest, and c) the structure of the compartment model can be made biologically realistic so that future health state projections (on which cost estimates are based) can be developed using extrapolation functions reflective of the disease incidence and progression mechanisms for identifiable cohorts.

With the general population as a target group, a compartment model which depicts the disease process as a series of degenerating health states is proposed herein as a useful model for incorporating multiple sources of information in developing estimates of cost for solid tumor cancers. The proposed method employs the standard actuarial techniques for discounting for interest and survivorship. In addition to estimating currently incurred costs, the methodology can be used to forecast future costs of specific diseases stratified by geographic region, sex, race or other demographic factors. The methodology is illustrated for cancer of the lung using tumor registry and mortality data.

Conceptually, cancer and other major chronic diseases may all be viewed as types of disability. In general, actuaries determine disability and pension benefit programs by using a two-step or primary-secondary decrement model. When examined in the context of this disability model, direct costs of treatment of a disease and direct costs of death due to the disease are mathematically equivalent, respectively, to annuities and death benefits of a disabled insured. The requisite disability data for implementing a primary-secondary decrement model (for example, disability experience of the Social Security Administration or the Railroad Retirement Commission) is relevant to a chronic illness such as cancer only insofar as the illness actually represents a disabling or debilitating condition in an individual. Therefore, explicit chronic illness experience, from onset to mortality, is generally not available, particularly for elderly people. Given onset of a chronic condition, mortality risks can be approximated using information gathered from medical follow-up studies such as those compiled by Singer and Levinson (1976). Estimates of onset times of, say, cancer can then be used to indirectly estimate the functions of a primary-secondary decrement table using Phillip's approximation (see Jordan, 1967). Unfortunately, estimates of disease latency and onset time, if available at all, are generally crude.

To get away from the select nature of the insurance industry experience and to provide a more representative estimate of local and national expenses, a variety of health care utilization and expenditure surveys have been performed with government funding. The Health Interview Survey (HIS) also gathers data on health care facility use. These surveys, however, are expensive to perform and suffer from significant sources of bias due to the fact that they only represent actual health service utilization, and obviously, utilization rates will vary due to a large number of factors other than primary health care needs.

To use these and other sources of health care expenditure information, the stratified actuarial methodology has been modified. Currently there are two variants of the actuarial methods used by planners; the prevalence method and the incidence method. The prevalence method of estimating costs assesses annual costs for each person with the disease. This is done for all diseases of interest. The annual cost per capita is an estimate of the cost incurred on the average for each person with the disease during the year. This method was introduced by Rice (1966) and her collaborators and is the basis for many of the national cost estimates for specific diseases employed by federal agencies (see also Cooper and Rice (1976)). The prevalence method is ideally suited for

estimating current year costs.

The incidence method of estimating costs assigns the cost of the entire disease, discounted over time, to the time of onset of the disease (Hartunian et al., 1981). For example, an individual with disease onset at time t will expect to pay, or have paid in his behalf, an amount each month for the rest of his life, assuming the disease is irreversible. To apply the incidence method, these direct and indirect costs at or after the time of disease onset are discounted back to the time of disease onset. Computationally, the discounting process to determine the cost assigned to onset of disease is very similar to the present value of a life annuity. The incidence method closely resembles the actuarial methodology and is more suitable for assessing the impact of health care planning and ameliorative programs than the prevalence method. Most other methods seem to be a modification of either the prevalence or incidence methods noted here.

To illustrate the application of the different cost estimation procedures for a general population, we will consider one particular chronic disease: cancer of the lung. A simplified schematic of the disease process is given in Figure 1. Here $\lambda_1(y)$ represents the hazard or instantaneous probability rate for an individual in the well state at age y, of having the clinical onset of lung cancer at age y. Similarly, $\lambda_2(y_0,t)$ is the hazard rate of an individual who had cancer onset at age y of dying due to lung cancer at age $y_0 + t$. The function $\mu(y)$ is the hazard rate for death due to other causes for a person aged y (whether or not there has been the onset of cancer). Note that the action of other causes is assumed to be independent of the presence of cancer. The function $\mu(y)$ is really a collection of forces of mortality due to all causes other than cancer of the lung. Using the model in Figure 1, let $N(\tau)$ denote the total number of individuals in the cancer state at age τ and $n(\tau)$ denote the number of individuals entering the cancer state at age τ. The prevalence method of estimating costs of disease consists of summing the incurred costs for all $N(\tau)$ individuals at age τ. The incidence method assigns a present value for all future expected costs to each of the $n(\tau)$ individuals with onset at age τ and then sums these.

We propose to use a compartment model method for generating the components of Figure 1. This method can be used on tumor registry data sets and underlying cause mortality data files. As a result, this methodology provides an inexpensive method for generating the morbidity parameters ($n(\tau)$ and $N(\tau)$) from currently available data.

The proposed method is not intended to supplant current survey methods or follow-up studies. Instead, it is intended to provide an inexpensive method of estimating population-wide cost figures. Further, because of the nature and scope of the core data utilized (i.e., national mortality statistics and population estimates of the U.S. census bureau), parameters can be estimated for specific demographic groups and for local areas (e.g., PSRO's or counties). In addition, since mortality data are collected on a continuing basis, one can, in effect, monitor changes in national health care needs on a "real time" basis and thus be sensitive to emerging changes in those needs.

Hence, in general terms, estimation of $n(\tau)$ or $N(\tau)$ (depending on whether the incidence or prevalence methodology is used) provides an inexpensively obtained population-wide estimate of costs. Methods of estimating $n(\tau)$ and $N(\tau)$ are given by Manton and Stallard (1979). Extension of these results to actuarial functions are in Tolley, et al. (1983).

APPLICATION OF THE MODEL

White male cohort mortality data on lung tumors in the U.S. for 28 calendar years, 1950 to 1977, were used to estimate the parameters of the model described above in Manton and Stallard (1982). From the estimated parameters, standard analytical methods can be used to form estimates of costs of cancer. In order to effect this, however, the functions giving costs of treatment and foregone earnings must be determined. Unfortunately, the available literature on costs aggregate these functions over time and/or age cohorts. Surveys for gathering such functions are incomplete, unavailable or still ongoing. However, since the median survival time of lung cancer after diagnosis is short (about 5.5 months), we can assume that the patient receives full treatment from the date of diagnosis. Consequently, to illustrate the proposed methodology, we will assume that the annual per capita costs for lung cancer treatment are $3667 per person. This is the per capita cost estimate obtained from the $730.5 million direct costs estimates for short-stay hospital care ($632.8 million) and physicians' services ($97.7 million) in 1977 for neoplasms of respiratory organs (Rice and Hodgson, 1981, p. 43). Specifically, the $730.5 million was pro rata allocated to white male lung cancer cases yielding $398.4 million to cover the costs of our projected 108,640 persons receiving treatment. The $3667 per capita cost estimate, in 1977 dollar units, represents the ratio of $398.4 million to 108,640 persons. Hence, we assume that the annual cost, $c_\tau(t)$, of treatment is constant, $3667, over age and time cohorts. For illustrative purposes we will assume the interest rate for discounting to be 6 percent.

Since $c_\tau(t)$ is constant we may simply approximate the present value of future costs, $\bar{a}^{\delta}_{\tau}$, by

$$\bar{a}^{\delta}_{\tau} = \$3667 \cdot \sum_{t=0}^{\infty} n_\tau(t + 1/2) \cdot (1.06)^{-t} \quad (1)$$

(see Jordan, 1967) where $n_\tau(t)$ is the number of the individuals who had tumor onset at age τ who are still alive at age $(\tau + t)$. Equation (1) is a result of using the midpoint rule to approximate integral expressions of costs. (A half year's interest is accumulated to $t + 1/2$.) In the actuarial literature such integrals are usually approximated using the trapezoid rule.

To estimate the indirect costs we will assume that the age specific present value of lifetime earnings presented in Rice (1981: p. 41) for males with a 6 percent built-in discount can be used to estimate the function giving foregone earnings, denoted $b_\tau(t)$. As above, we employ a midpoint approximation to obtain the present value of the indirect costs or foregone earnings, $\bar{A}^{\delta}_{\tau}$:

$$\bar{A}^{\delta}_{\tau} = \sum_{t=0}^{\infty} b_{\tau}(t) \cdot n_{\tau}(t + 1/2)$$

$$\cdot \lambda_2(\tau, t + 1/2) \cdot (1.06)^{-t} . \quad (2)$$

One further adjustment to both (1) and (2) is to restrict the summation to the first w years of tumor treatment to reflect the effects of a cure. However, this is equivalent to setting $b_{\tau}(t)$ and $c_{\tau}(t)$ to zero for $t > w$, implying that a cure may be defined solely in terms of economic costs.

Applying equations (1) and (2), and then grouping values of τ in four broad intervals, we get the distribution of costs by age at onset of tumor (Table 1). Recall that this is the incidence method of assessing costs. The prevalence method could also be used given the estimated parameters (w = 20.5 here, see Tolley et al. 1983).

Table 1 indicates that the total economic costs of the 72,408 diagnosed cases of lung cancer is almost $3.9 billion. However, over 90 percent of this total cost is due to the lifetime earnings lost due to premature lung cancer death. The direct cost expenditures are $375 million with $188 million incurred by those white males in the over 65 age group. Note that our $3.5 billion indirect cost estimate compares favorably with the 4.0 billion estimate provided by Rice and Hodgson (1981; p. 42), if it is remembered that the Rice and Hodgson estimate also includes nonwhite males and is based on the prevalence rather than the incidence method of calculation.

If diagnosis were made "earlier" with regard to tumor growth, i.e., when the tumor was still only localized, the chances of survival would be increased. However, since the direct costs of treatment are assumed constant, the total direct costs for the disease will increase. This is reflected in Table 2 where the transition parameters are changed to reflect the slower rate of transition from the tumor growth state to the death by tumor state.

The increase from 72,408 to 81,588 diagnosed white males is due to the assumption that the diagnosis occurs 8.3 percent earlier in the tumor growth process (Manton and Stallard, 1982). Although the number of diagnosed cases increases by 12.7 percent, Table 2 shows that the total costs increase by only 3.2 percent. However, the indirect costs decrease by 16 percent, with the net increase in the total costs being due to the 179.2 percent increase in direct costs. This dramatic increase in direct costs is due to the assumption that $c_{\tau}(t)$ is constant for all values of $t < w$. A more realistic approach would probably model $c_{\tau}(t)$ as a decreasing function to reflect, after the first few years of treatment, a reduction in the amount of treatment. Better estimates would be obtained if health care economists assembled the types of data from which empirical estimates of $c_{\tau}(t)$ could be made, i.e., explicit measurements of the temporal trajectory of costs from the time of diagnosis to death or cure.

For health planners, the future direct costs of disease are of particular interest. Assuming no inflation (i.e., using current dollars), the distribution in 1977 dollars of costs of disease for 1977, 1980, 1990 and 2000 are given in Table 3. In order to project the demographic make-up, the force of mortality due to non-cancer causes was assumed constant from 1978 through 2000. Table 4 gives the corresponding cost projections when the projected total adult populations are standardized by age to that of 1977.

Table 3 indicates that by the year 2000, there will be a 67 percent increase in the treatment costs for lung cancer for U.S. white males, the total treatment costs being over $665 million in 1977 dollars. If one wished to assume, say, a 10 percent rate of inflation over the 23 year period, then the projected treatment costs would be over $5.96 billion.

Table 4 indicates that just under half of the increase in treatment costs is due to a projected increase in lung cancer prevalence, the remainder being due to the demographic shift in the population to older ages. However, both tables show that the elderly population (age 65 and older) will be the most heavily affected by these two dynamics. That is, by 2000 we can anticipate a much larger elderly population with a much higher prevalence of lung cancer than we observe today.

DISCUSSION

In the preceding sections, we have illustrated how compartment models can be integrated with standard actuarial methods to generate cost estimates for specific diseases for populations with deficient experience data. In order to adjust for deficiencies in experience data, the compartment model is structured to represent the mechanisms of disease incidence and progression, and to employ auxiliary health survey data of an indirect type, in order to produce more realistic extrapolation of costs.

The need for such methodologies in actuarial science is becoming clear because of certain recent trends. First, due to population aging and rapidly rising health care costs, there is a desire on the part of government to more fully involve the private sector in health coverage for a wider range of population groups (e.g., the elderly). Obviously, the experience base for such groups does not currently exist. Second, with an increase in life expectancy, and greater proportions of the population surviving to advanced ages, or surviving with chronic conditions, there has been a rapid rise in medical care costs--much of which is borne by third party contractors. As a consequence, it could be useful to have a methodology that could reflect the cost implications of efforts at primary prevention and maintenance of population "wellness" to determine if expenditures in this direction were cost effective. The proposed methodology, which allows the simulation of the cost implications of various health interventions, can provide such estimates.

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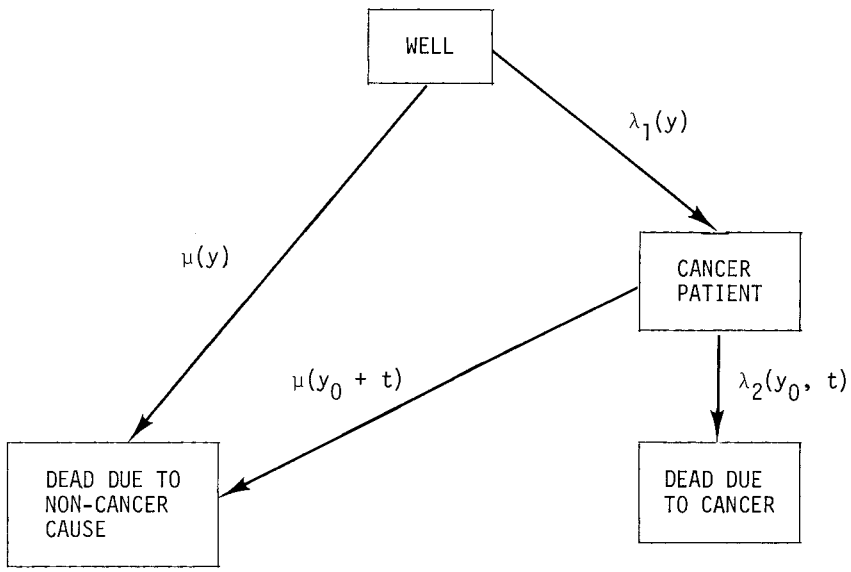

FIGURE 1. Compartment model of cancer treatment and mortality.

TABLE 1. Age specific costs of lung cancer for U.S. white male incidence in 1977. (1977 Dollars)

	Costs in Thousands of Dollars at 6% Discount			
Age	Total*	Direct	Indirect	n_τ
0-44	443,191	11,194	431,999	1,813
45-64	2,869,681	175,916	2,693,763	30,688
65-74	466,649	125,742	340,907	24,993
75-97	112,311	62,148	50,164	14,914
Total*	$3,891,833	$375,000	$3,516,833	72,408

NOTE: Numbers may not add to totals due to rounding.

TABLE 2. Hypothetical age specific costs of lung cancer for U.S. white male incidence in 1977 assuming "early" diagnosis. (1977 Dollars)

	Costs in Thousands of Dollars at 6% Discount			
Age	Total*	Direct	Indirect	n_τ
0-44	492,380	41,067	451,313	2,567
45-64	2,768,395	530,574	2,237,822	36,509
65-74	577,807	331,580	246,229	27,244
75-97	177,035	143,607	33,429	15,266
Total*	$4,015,620	$1,046,828	$2,968,792	81,588

NOTE: Numbers may not add to totals due to rounding.

TABLE 3. Age specific costs of lung cancer treatment for U.S. white males in 1977, 1980, 1990 and 2000. (1977 Dollars)

	Costs in Thousands of Dollars			
Age	1977	1980	1990	2000
0-44	5,516	5,829	8,257	9,315
45-64	137,926	146,964	168,908	193,569
65-74	143,093	155,583	199,586	231,829
75-97	111,851	129,878	187,434	230,932
Total*	$398,384	$438,253	$564,185	$665,647

NOTE: Numbers may not add to totals due to rounding.

TABLE 4. Standardized age specific costs of lung cancer treatment for U.S. white males in 1977, 1980, 1990 and 2000: Standard population in 1977 U.S. white male age distribution. (1977 Dollars)

	Costs in Thousands of Dollars			
Age	1977	1980	1990	2000
0-44	5,516	5,511	5,511	5,511
45-64	137,926	144,592	167,558	169,660
65-74	143,093	146,631	164,444	198,378
75-97	111,851	122,486	145,791	154,226
Total*	$398,384	$419,218	$483,303	$527,773

NOTE: Numbers may not add to totals due to rounding.