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COMPARTMENT MODEL METHODS IN ESTIMATING CANCER COSTS

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ABSTRACT

Efficient public planning and policymaking in the health care sector frequently require the availability of good estimates of current and future costs of disease. Typically, such estimates are obtained for select populations on the basis of health care expenditures for specific diseases in prior years. Although such experience data are fully utilized by the insurance industry to estimate current and future costs and to set the proper premium levels for coverage, these data do not permit cost extrapolation beyond the select population from which they are gathered. In response to these data and methodological issues, we propose to use 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. By combining these estimated numbers of persons with per capita treatment cost estimates using standard actuarial methods, current and future estimates of both direct and indirect costs of disease can be obtained. 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 United States white male lung cancer morbidity and mortality data from the period 1950–77.

I. INTRODUCTION

In this paper, we propose the use of stochastic compartment model methods for estimating both the current direct and the current indirect

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costs of specific cancers and for forecasting future direct and indirect costs. Since the purpose of the estimates in this paper is assumed to be primarily public planning and policymaking, we must consider the health risks of the general population rather than simply those of a select population such as an insured cohort. Consideration of the general population entails additional problems in that there are 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 future costs are projected. In either case, more accurate cost projections can be developed if (*a*) standard actuarial methodology can be adapted to a 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 by using extrapolation functions reflective of the disease incidence and progression mechanisms for identifiable cohorts.

With the general population as the target group, a compartment model that 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 of 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 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 indirect 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 (e.g., disability experience of the Social Security Administration or the Railroad Retirement Commission) are 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

the 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 [12]. Estimates of onset times of, say, cancer then can be used to estimate indirectly the functions of a primary-secondary decrement table using Phillips's approximation (see Jordan [7]). 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 because they represent only actual health service utilization and, obviously, utilization rates will vary as the result of a large number of factors other than primary health care needs.

To use these and other sources of health care expenditure information, the standard actuarial methodology has been modified. Currently there are two variants of the actuarial methods used by planners, the prevalence method and the incidence method.[1] 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 and her collaborators [10] and is the basis for many of the national cost estimates employed by federal agencies for specific diseases (see also Cooper and Rice [5]). 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 [6]. For example, an individual with disease onset at time t will expect to pay, or to have paid in his behalf, an amount each month for the rest of his life, assuming that 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 as-

[1] The incidence method and the prevalence method of estimating costs are based upon different accounting conventions for defining cost. The two methods are *not* different procedures of estimating the same incurred obligations.

sessing 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 the incidence method noted here.[2]

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. In this diagram, $\lambda_1(y)$ 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_0 of dying of 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

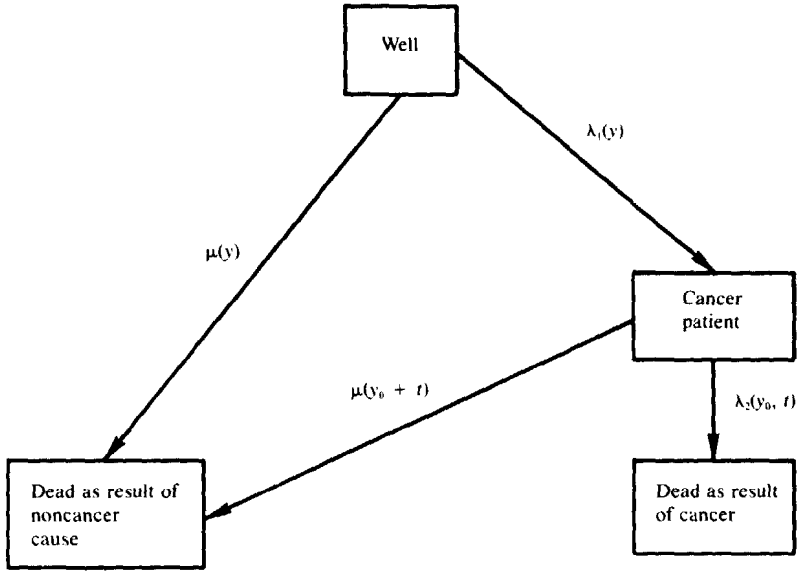

FIG. 1.—Compartment model of cancer treatment and mortality

[2] As pointed out by a referee, a change in time of diagnosis would change reported costs under the incidence method even if the change had no effect on cash expenditure. For diseases such as cancer of the lung, time of diagnosis determines initiation of primary care. We assume here that, in general, time of diagnosis and start of health care delivery are closely related.

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 United States Bureau of the Census), parameters can be estimated for specific demographic groups and for local areas (e.g., PSROs or counties). In addition, since the 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 the prevalence methodology is used) provides an inexpensively obtained population-wide estimate of costs.

II. PRELIMINARIES

We define the following parameters:

δ = Instantaneous discount rate for determining present values. If i is the annual interest rate, then $\delta = \log(1 + i)$.

$c_\tau(t)$ = Instantaneous costs (at an annual rate) of the disease at time t units (years) after onset at age τ. These costs typically include medical costs, costs due to loss of work, and other direct costs to the individual or a third-party benefactor.

$b_\tau(t)$ = Instantaneous costs (at an annual rate) of death due to cancer occurring t time units (years) after onset of tumor at age τ. This cost is usually an indirect cost due to lost future lifetime earnings, societal loss, and so forth.

$d_\tau(t)$ = Direct cost of dying, including funeral costs, probate, and so forth.

Using these definitions, we can express the present value of the direct costs to an individual with cancer onset at age τ as

$$\bar{a}_\tau^\delta = \int_0^\infty [c_\tau(t) + d_\tau(t)\lambda_2(\tau, t)] \times \exp(-t\delta) \exp\left\{-\int_0^t [\lambda_2(\tau, x) + \mu(\tau + x)]dx\right\}dt . \tag{1}$$

Similarly, the present value of the indirect costs incurred at death for an individual with disease onset at age τ is given by

$$\bar{A}_\tau^\delta = \int_0^\infty b_\tau(t)\lambda_2(\tau, t) \times \exp(-t\delta) \exp\left\{-\int_0^t [\lambda_2(\tau, x) + \mu(\tau + x)]dx\right\}dt . \tag{2}$$

For examples of the development, use, and approximation of these integral expressions see Jordan [7]. One can see that $\bar{a}_\tau^\delta$ and $\bar{A}_\tau^\delta$ represent, respectively, the direct and indirect costs of the disease obtained by using the incidence method.

For an individual aged τ at onset of disease, the prevalence method expresses the direct costs from y to $y + 1$ years after onset as

$${}_{y|1}\bar{a}_\tau^0 = \int_y^{y+1} \exp\left\{-\int_0^t [\lambda_2(\tau, x) + \mu(\tau + x)]dx\right\} \times [c_\tau(t) + d_\tau(t)\lambda_2(\tau, t)]dt . \tag{3}$$

Similarly, indirect costs are given by

$${}_{y|1}\bar{A}_\tau^0 = \int_y^{y+1} \exp\left\{-\int_0^t [\lambda_2(\tau, x) + \mu(\tau + x)]dx\right\} b_\tau(t)\lambda_2(\tau, t)dt . \tag{4}$$

It is easy to see that an estimate of the functions $\lambda_2(y_0, t)$, $\mu(y)$ and the cost functions are sufficient to estimate individual costs under both models. Population costs are the summation of costs of each individual of each age cohort. For the incidence method these are given as

$$\bar{a}^\delta = \int_0^\infty n(\tau)\bar{a}_\tau^\delta d\tau \tag{5}$$

and

$$\bar{A}^{\delta} = \int_0^{\infty} n(\tau)\bar{A}_{\tau}^{\delta} d\tau \,, \tag{6}$$

where calendar time is fixed and τ represents the different ages of individuals entering chronic disease state at this fixed time. In practice, both of these functions will be estimated on an annual basis rather than at a point in time.

III. THE MODEL

In order to model observed morbidity and mortality data, the functions $\mu(\cdot)$, $\lambda_1(\cdot)$ and $\lambda_2(\cdot, \cdot)$ must be parameterized. Since the action of other causes of death is assumed independent of cancer onset, $\mu(y_0 + t) = \mu(\tau)$ whenever $\tau = y_0 + t$. Hence, the age-specific death rate for deaths due to other causes among the individuals with a tumor is estimable from the observed death rate of non-lung-tumor deaths.

A second assumption is in regard to the function $\lambda_1(y)$. For many chronic diseases there is a lengthy developmental period. At some point during that development the disease progresses to the point where the most advanced chronic disease becomes clinically manifest. For example, models of cancer progression suggest that many tumors initiate from a single cell and grow exponentially with a fixed doubling time that is determined by the characteristics of the host organism. At 32–34 doublings the tumor is at a clinical threshold, and at 40 doublings it is of a potentially lethal size. Actual diagnosis may occur at any intermediate number of doublings [1]. In this case, Manton and Stallard [9] show that a reasonably good approximation to the transition rate $\lambda_1(y)$ is obtained from

$$\lambda_1(y) = -\frac{\partial}{\partial y} \ln \left(\int_y^{\infty} \int_0^{y_0} \frac{\tilde{\alpha}(y_0 - l)^{m-1} \exp\{-[\ln(l/\bar{l})]^2/2\sigma^2\}}{[1 + \gamma(y_0 - l)^m/m]^{(1+\tilde{\alpha}/\gamma)} l\sigma(2\pi)^{1/2}} \, dl dy_0 \right). \tag{7}$$

In expression (7) the five parameters $\tilde{\alpha}$, m, γ, $\bar{l}$, and σ have the following interpretations:

$\tilde{\alpha}$ = Average level of susceptibility to tumor initiation among all persons in a given cohort;
m = Number of mutations in cell nuclei before cell becomes cancerous;

γ = var $(\alpha)/\bar{\alpha}$
= Adjustment for individual differences in susceptibility to tumor initiation, where $\bar{\alpha}$ is the mean of the α's and where the α's are assumed to be gamma distributed;

$\bar{l}$ = Median tumor growth latency time between onset of tumor at the level of a single cell and diagnosis at between 30 and 40 tumor volume doublings;

σ = $\{\text{var } [\ln (l)]\}^{1/2}$
= Adjustment for individual differences in the rate of tumor growth, where $\bar{l}$ is the median of the l's and where the l's are assumed lognormally distributed.

Equation (7) is based on the convolution of two well-known hazard functions: (1) the multistage incidence function proposed by Armitage and Doll [2] and (2) the exponential growth model proposed by Collins et al. [4]. For both function types, we have added parameters to adjust for individual differences. This latter adjustment is required, since we estimate the model parameters from cohort data representing aggregates of individuals having differential tumor incidence risks and differential tumor growth rates.

The third assumption is in regard to the function $\lambda_2(y_0, t)$. This function represents the force of mortality due to lung cancer among diagnosed lung cancer patients. This function may be parameterized using clinical survival information from an appropriate source. For lung cancer we used the relative survival rates at 1, 3, 5, 10, and 15 years beyond diagnosis reported in Axtell et al. [3] to construct estimates of $\lambda_2(y_0, t)$ as a simple step function of time since diagnosis, t, but not of age at diagnosis, y_0.

A fourth assumption is in regard to a method of accounting for the possibility of cure. Although for most chronic diseases the question of cure is rarely an issue (e.g., how does one cure arteriosclerosis?), for cancer there is a growing body of evidence that new surgical and chemotherapeutic techniques, combined with better detection methods, do indeed lead to cures in some patients. Thus, one strategy (the one we will use) for dealing with such cures is to find the disease treatment time, w, at which the relative survival curve becomes flat, that is, nondecreasing. Obviously, for treatment times longer than this cure time, $\lambda_2(y_0, t) = 0$, implying a zero mortality hazard. Naturally, this raised two issues: (1) whether one should continue to assess the direct cost $c_1(t)$ for the population component with $t > w$ and (2) whether the full cost $c_1(t)$ should be assessed for values of t "near" w, that is, for a population component in which a substantial proportion of the persons are already cured.

Finally, we need to obtain an expression for the lung cancer death rates in the population. The probability that an individual just born will die of lung cancer between ages x and $x + \Delta x$, assuming that no other causes of death are operating, is given by $f(x)\Delta x$, where

$$f(x) = \int_{x-w}^{x} \lambda_1(y) \exp\left[-\int_0^{y} \lambda_1(t)dt\right] \lambda_2(y, x - y) \times \exp\left[-\int_0^{x-y} \lambda_2(y, t)dt\right] dy , \tag{8}$$

where the integration lower limit $x - w$ is replaced with zero if $w > x$. The probability that an individual alive at age x will die of lung cancer between ages x and $x + \Delta x$, assuming that no other causes of death are operating, is given by $\lambda(x)\Delta x$, where

$$\lambda(x) = -\frac{\partial}{\partial x} \ln\left[\int_x^{\infty} f(t)dt\right] . \tag{9}$$

Equation (9) is the instantaneous lung cancer death rate in the population. This function is an amalgamation of both λ_1 and λ_2 through the use of the convolution equation (8).

With the preceding assumptions in place, it is now possible to estimate the parameters $\bar{\alpha}$, m, γ, $\bar{l}$, and σ in Figure 1. Iterative methods such as nonlinear least squares have been proposed for such models (Tolley et al. [13]). Computationally more tractable, however, is the likelihood argument given by Manton and Stallard [8]. Since each individual's mortality and tumor response are independent of those of any other individual, and since response patterns are, a priori, identically distributed, the probability that d_y lung cancer deaths will occur at age y conditional on D_y total deaths has a binomial distribution. Furthermore, it is shown in Manton and Stallard [9] that the marginal distribution of d_y lung cancer deaths will be well approximated by the Poisson distribution with $\lambda(x)$ in equation (9) being multiplied by the population size to represent the expected number of lung cancer deaths. Given these assumptions, a product Poisson likelihood equation can be formed and employed to estimate values of the parameters $\bar{\alpha}$, m, γ, $\bar{l}$, and σ. Formation and estimation of this equation are given in Manton and Stallard [9].

IV. APPLICATION OF THE MODEL

White male cohort mortality data on lung tumors in the United States for twenty-eight calendar years, 1950–77, were used by Manton and Stallard [9] to estimate the parameters of the model described above. Substituting these estimated parameters in equations (5) and (6) and using standard analytical methods will yield estimates of cancer costs. In order to effect this, however, the functions $b_\tau(\cdot)$, $c_\tau(\cdot)$, and $d_\tau(\cdot)$ need to be determined. Unfortunately, the available literature on costs aggregates 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 \$3,667 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 ([11], p. 43). Specifically, the \$730.5 million was allocated on a pro rata basis to white male lung cancer cases, yielding \$398.4 million to cover the costs of our projected 108,640 persons receiving treatment. The \$3,667 per capita cost estimate, in 1977 dollar units, represents the ratio of \$398.4 million to 108,640 persons. Hence we assume that $c_\tau(t)$ is constant, \$3,667, over age and time cohorts. For illustrative purposes we will set $d_\tau(t) = 0$ and estimate $\bar{a}^\delta$, the direct cost of lung cancer, assuming $c_\tau(t) = \$3{,}667$ for all t and τ, and assuming an annual interest rate of 6 percent.

Since $c_\tau(t)$ is constant, we may simply approximate $\bar{a}^\delta_\tau$ by

$$\bar{a}^\delta_\tau = (\$3{,}667)\sum_{t=0}^{\infty} n_\tau(t + \tfrac{1}{2})\,(1.06)^{-t}, \tag{10}$$

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 (10) is a result of using the midpoint rule to approximate integrals of the type given in equation (1). (A half-year's interest is accumulated to $t + \frac{1}{2}$.) In the actuarial literature such integrals are usually approximated using the trapezoidal rule.

To estimate the indirect costs, we will assume that the age-specific present value of lifetime earnings presented by Rice and Hodgson ([11],

p. 41) for males, with a 6 percent built-in discount, can be used to estimate $b_\tau(t)$. As above, we employ a midpoint approximation to obtain $\bar{A}^{\delta}_{\tau}$:

$$\bar{A}^{\delta}_{\tau} = \sum_{t=0}^{\infty} b_\tau(t) n_\tau(t + \tfrac{1}{2}) \lambda_\tau(\tau, t + \tfrac{1}{2})(1.06)^{-t}. \tag{11}$$

One further adjustment to both equations (10) and (11) 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 (10) and (11), 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.

Table 1 indicates that the total economic cost 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 because of 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 ([11], 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, that is, when the tumor was still only localized, the chances of survival would

TABLE 1

AGE-SPECIFIC COSTS OF LUNG CANCER FOR UNITED STATES WHITE MALE INCIDENCE IN 1977

(1977 Dollars)

AGE	COSTS (000) AT 6% INTEREST			n_τ
	Total*	Direct	Indirect	
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

* Numbers may not add to totals because of rounding.

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 [9]. 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, that is, 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 makeup, the force of mortality due to noncancer 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 2

HYPOTHETICAL AGE-SPECIFIC COSTS OF LUNG CANCER FOR UNITED STATES WHITE MALE INCIDENCE IN 1977, ASSUMING "EARLY" DIAGNOSIS

(1977 Dollars)

AGE	COSTS (000) AT 6% INTEREST			n_τ
	Total*	Direct	Indirect	
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

* Numbers may not add to totals because of rounding.

Table 3 indicates that by the year 2000, there will be a 67 percent increase in the treatment costs for lung cancer for United States 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 twenty-three-year period, then the projected treatment costs would be over $5.96 billion.

Table 4 indicates that just under half 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. In other words, by the year 2000 we can anticipate a much larger elderly population with a much higher prevalence of lung cancer than we observe today.

TABLE 3

AGE-SPECIFIC COSTS OF LUNG CANCER TREATMENT FOR UNITED STATES WHITE MALES IN 1977, 1980, 1990, AND 2000

(1977 Dollars)

AGE	COSTS (000)			
	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

* Numbers may not add to totals because of rounding.

TABLE 4

STANDARDIZED AGE-SPECIFIC COSTS OF LUNG CANCER TREATMENT FOR UNITED STATES WHITE MALES IN 1977, 1980, 1990, AND 2000: STANDARD POPULATION IN 1977 UNITED STATES WHITE MALE AGE DISTRIBUTION

(1977 Dollars)

AGE	COSTS (000)			
	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

* Numbers may not add to totals because of rounding.

V. DISCUSSION

In the preceding sections, we have examined how compartment models can be integrated with standard actuarial methods to generate cost estimates for specific diseases for populations with limited experience data. 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, to produce more realistic extrapolation of costs.

The need for such methodologies in actuarial science is becoming clear because of certain recent trends. First, as a result of population aging and rapidly rising health care costs, there is a desire on the part of government to involve the private sector more fully 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 with 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. It would be useful to have a methodology that could reflect the cost implications of efforts at primary prevention and maintenance of population "wellness" to determine whether 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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