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Modelling the Age Dynamics of Chronic Health Conditions: Life-Table-Consistent Transition Probabilities and Their Application

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SEDAP Research Paper No. 288

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MODELLING THE AGE DYNAMICS OF CHRONIC HEALTH CONDITIONS: LIFE-TABLE-CONSISTENT TRANSITION PROBABILITIES AND THEIR APPLICATION

Abstract

We derive transition probability matrices for chronic health conditions using survey prevalence data. Matrices are constructed for successive age groups and the sequence represents the "age dynamics" of the health conditions for a stationary population – the probabilities of acquiring the conditions, of moving from one chronic conditions state to another, and of dying. One can simulate the life path of a cohort under the initial probabilities, and again under altered probabilities to explore the effects of eliminating a particular condition or reducing its mortality probabilities. We report the results of such simulations and note the general applicability of the methods.

Résumé

Nous calculons les matrices de probabilités de transition associées aux problèmes de santé chroniques à partir de données d'enquête de prévalence. Les matrices sont construites pour tous les groupes d'âge successifs et la séquence représente l'évolution de l'état de santé en fonction de l'âge d'une population stationnaire - la probabilité d'acquérir une maladie, de passer d'une maladie chronique à l'autre, et de mourir. On peut ainsi simuler le chemin de vie d'une cohorte en tenant compte des probabilités d'occurrence initiales, et aussi en considérant des probabilités modifiées pour explorer les effets de l'élimination d'une condition particulière ou la réduction de son taux de mortalité. Nous rapportons les résultats de ces simulations et l'applicabilité générale de nos methods.

Key Words: Chronic health conditions; Transition probabilities; Age dynamics

JEL: Classification: I19, J19

INTRODUCTION

Surveys of chronic health conditions provide information about the prevalence of such conditions in the population and repeated surveys provide information about changes in prevalence. The Canadian Community Health Survey (from which we draw data in this paper) is a good example. Among other things it asks of random sample respondents whether they have one or more of over thirty different chronic conditions, ranging from allergies, migraine headaches, and back problems to cancer, heart disease, and dementia. It provides a broadly based "snapshot" of prevalence among males and females of different ages. What the survey (and others like it) does not do is provide direct information about the *incidence* of chronic conditions and the process of change within the population – about the probabilities of contracting the conditions at different ages, of moving from one chronic conditions state to another, and of dying. We refer to this process as the "age dynamics" of chronic conditions and show how the characteristics of the process can be inferred from prevalence data for those conditions that can be viewed as irreversible.

We define different states of the process for a selected set of chronic conditions – "good health", single chronic conditions, multiple conditions, and death – and estimate the probabilities of moving from one state to another. To do so we make use of data from the survey noted above in combination with data from Canadian life tables. We construct a matrix of state transition probabilities for each of males and females in different age groups. For each sex we combine the matrices to form a consistent age sequence, starting with ages 20-24, and embed the sequence in a stationary population defined by the life tables. The matrices are of interest in themselves, but beyond that, the combined sequence provides a tool for carrying out interesting computer experiments. Starting with the youngest age group, one can simulate the time path of chronic conditions prevalence rates and survival rates over the life span under alternative assumptions. One can do "what if" experiments: What if current probabilities remain the same and a cohort starts out at 20-24 with no chronic conditions; what would be the expected prevalence rates by the time the cohort is 40-44, 50-54, etc.? What if cancer were to be eliminated, with corresponding adjustments to the probability matrices; what then would be the expected prevalence rates? What would happen to life expectancies at different ages? What if the probabilities of becoming diabetic were to be cut in half; how would life expectancies be affected and what would be the effects on the requirements for hospital and other health care services? We develop the framework that makes such calculations possible and show the results of a number of experiments of this kind.

One aim of our paper is to describe the framework so as to be able to present the results of the experiments. Another, though, is to provide a demonstration piece. We use particular data sets and experiment with a particular set of chronic conditions but the methods we use are of general applicability. They can be applied to chronic conditions data from other surveys and other selections of particular conditions, as long as the conditions (like those that we experiment with) can be regarded as irreversible.

The paper proceeds as follows. We start with the definition of a chronic condition, in particular the requirement of irreversibility. We relate what we are doing to the assumptions underlying the standard

demographic life table and note that our framework can be viewed as an extension of the life table. We develop the theoretical framework for the transition probability matrices, provide some discussion of the proper interpretation of the death probabilities, and show how the matrices for different age groups can be linked to form a consistent sequence. We describe the data that we use and how the probability matrices can be constructed from the data, making use of a method known as iterative proportional scaling in the statistics literature, or the RAS method in the literature on input-output modelling. We then carry out and interpret a series of experiments, first assuming no changes in the initial probabilities and then assuming a number of hypothetical or "what if" changes – different scenarios, as we call them. We extend the scenario results by adding calculations of the effects on life expectancies and on the requirements for selected health care services. We conclude with a brief note on possible future applications of our framework and methods.

THE DEFINITION OF A CHRONIC CONDITION

The chronic conditions health states that we define must be interpretable as irreversible. Not all chronic conditions covered by surveys satisfy that requirement and whether they do may depend on the wording of the questions. Consider, for example, the following alternative wordings of a question about cancer: (1) "Do you have cancer?" (2) "Have you ever been diagnosed with cancer?" A survey respondent who had a cancerous tumour successfully removed surgically could have said "yes" to question (1) just before the surgery but "no" to the same question five years later. However, the same respondent would have had to say "yes" to question (2) at both times. Thus, by inference, the condition is reversible in the first case, irreversible in the second. Cataracts (removable by surgical lens implantation) provide a second example in which the wording of the question is important; hypertension (treatable by dietary change or drug therapy) provides a third. In addition to flows among health states we are concerned with deaths – flows into the "dead state" , which is obviously an irreversible or "absorbing" state.

The importance of irreversibility for our purposes is that it means that *net* flows of population from one state to another can be interpreted as *gross* flows. That is the key idea that allows us to construct state transition matrices from chronic conditions survey data.

SIMILARITY AND CONSISTENCY WITH THE LIFE TABLE

The *similarity* of our framework with the approach taken in constructing a life table comes about as follows. The standard life table (or period table, as it is called in the demographic literature) is derived from age-specific death probabilities based on the observed population mortality rates of a given year or other short period. What the table does is to draw out the implications of the death probabilities for survival and life expectancy at different ages. The survivors then constitute a stationary population, one in which the population size and age distribution remain constant over time. No attempt is made in the standard table to anticipate future changes in probabilities and their consequences. Rather, it

represents a useful tool for studying the implications of the probabilities current at a given time. What we do in this paper is similar in that we calculate age-specific probabilities of transition among health and mortality states based on data at a given time and derive the implications of those probabilities for a stationary population in which they remain unchanged. One can experiment with changes in the life table death probabilities and calculate the resultant new stationary population (see Keyfitz and Carswell, 2005, Chapter 14, for example); in the same way, one can (and we do) experiment with changes in our health state transition probabilities and observe the consequences. As in the life table, though, changes in probabilities over time are not incorporated into the framework.

The *consistency* of our framework with the standard life table arises from the fact that life table death probabilities are incorporated directly into the framework. The overall probability of dying between some age x and subsequent age x + 1 serves as a control on the health-state-specific probabilities of dying; the overall probability at each age is in effect allocated among health state components. The transition probabilities thus relate to a stationary population identical, in demographic characteristics, to the life table population.

TRANSITION FLOWS AND PROBABILITIES

We provide in this section a formal description of the transition model. Let x stand for age and assume a population of given size at some initial age (call it x = 0). Assume also n (irreversible) chronic conditions. At any age x > 0 a member of the initial population may have none of these conditions, one of them, two of them, three of them, etc., or may be dead. The total number of health states at any age (including good health and the dead state) is then G(n) = $\sum_{r=0}^{n} nCr + 1$ where nCr is the "n select r" combinatorics symbol. Examples are G(2) = 5, G(3) = 9, G(4) = 17, and G(5) = 33. In general

$G(n) = 2^n + 1$. The form of the model allows for any number n of chronic conditions but the resulting number of health states grows rapidly as n increases.

Now assume age to be recorded at uniform intervals and visualize a *transition flow* matrix F for some age x. The rows represent the possible health states at x and the columns represent the same states at x + 1; a typical element, f_{ij} , represents the number of people who move from state i to state j. With n individual chronic conditions, F is a G(n) x G(n) matrix with $G(n)^2$ elements. If n = 3, for example, F is 9 x 9 and there are 81 elements. However, not all elements represent admissible flows; many are zero because of the irreversibility restriction on chronic conditions.

Anticipating our numerical application later, suppose there are three chronic conditions: cancer, C, stroke/heart condition, S, and diabetes, D, all of them defined as irreversible. The "healthy" state (alive, with an absence of C, S, and D) is denoted by H and the dead state by X. The nine states are then H, C, S, D, CS, CD, SC, CSD, and X, where a double-letter state indicates the presence of two chronic conditions, the triple-letter state the presence of all three. Someone in H can move to any of the other states. Someone in C, say, can remain in the same state or move only to CS, CD, CSD, or X; someone in CS can move only to CSD or X. That is, once a "C label" is attached to an individual, only X or a state that also

has a C label is attainable. (The individual could not move from CS to SD, for example.) Irreversibility implies that someone who has once been diagnosed with cancer will always have been diagnosed with cancer, whether or not one or more other conditions are also present at a future time.

The form of the 9 x 9 flow matrix is shown in Table 1. A check mark indicates that a flow is admissible, a 0 that it is not. Of the 81 elements in the matrix, 36 are admissible, 45 are inadmissible. The general rule for a G(n) x G(n) matrix is as follows: Let $K(n) = G(n)^2$ be the total number of elements in F. The number of positive (that is, admissible) elements is then given by

$$K(n,+) = G(n) + \sum_{q=1}^{n-1} nCq[2 + \sum_{k=1}^{n}(n-q)Ck] + 3.$$

To provide some interpretation, G(n) at the beginning of the formula represents the number of attainable states in the first row of the matrix, the H row. (All states are attainable from the H state.) The 3 at the end represents the last and the second-to-last rows, i.e., the X row and the one for the simultaneous presence of all chronic conditions: being dead at age X implies only one possibility, being dead also at age x + 1; being in the all-conditions state at x allows only two possibilities, staying in that state or dying. The combinatorial terms in the middle of the formula represent the remaining rows of the matrix, in which the only possibilities are staying in the same state, dying, or moving to a higher-level state, one with one or more additional chronic conditions. Examples are the following:

n = 2, G(n) = 5, K(n) = 25, K(n,+) = 14, K(n,+)/K(n) = .560

n = 3, G(n) = 9, K(n) = 81, K(n,+) = 36, K(n,+)/K(n) = .444

n = 4, G(n) = 17, K(n) = 289, K(n,+) = 98, K(n,+)/K(n) = .339

n = 5, G(n) = 33, K(n) = 1,089 K(n,+) = 276, K(n,+)/K(n) = .253

K(n,+) increases as n increases but declines as a proportion of K(n).

The *transition probability* matrix, P, is derived from F in a straightforward manner. Let F_i. be the (positive) row i total and let p_{ij}, the i,j element of P, be the probability of moving from state i at age x to state j at age x + 1, or equivalently, the probability of an individual being in state j at x + 1, conditional on being in state i at x. Given F, the calculation is then $p_{ij} = f_{ij}/F_i$. (i,j = 1,2,…,G(n)). The number of positive elements is the same in P as in F.

INTERPRETING THE DEATH PROBABILITIES

The death probabilities, in particular, need to be interpreted with care. The probability of dying for someone in the C state is *not* the probability of dying from cancer. Rather it is the probability of dying, *for any reason* for someone *who has been diagnosed with cancer*. Someone who has been so diagnosed may indeed die of cancer but he/she may also die as a result of a motor accident, an infectious disease, or some other cause that is not included among the selected chronic conditions, and which may or may or not be related in any way to the cancer. Also, it is possible for someone in the "healthy" state, H, at

age x to be diagnosed subsequently with cancer and to be dead by that cause at age x + 1 *without ever passing through the C state in the model.* The shorter the interval between x and x + 1 (a month, a year, five years), the higher the degree of resolution, and the less likely is that to happen – the less likely is the individual never to be observed in the C state before death. However, with discrete intervals there is always a nonzero probability of it happening. Similarly, there is always a nonzero probability of someone in the C state at age x being dead of a stroke or heart attack at age x + 1 without ever passing through the CS state. That is an unavoidable consequence of using discrete intervals in the age classification.

There is a large and informative literature analysing the probabilities of dying, by cause of death, and the effects of reducing or eliminating particular causes. (The elimination of cancer has received considerable attention, for example.) Without attempting to be exhaustive, we note the following: an early contribution is Keyfitz (1977); a selection of more recent ones includes Nusselder et al. (1996), Mackenbach et al. (1999), Manuel et al. (2003), Kintner (2004; see "Cause-Elimination Life Tables"), Somerville and Francombe (2005), and Beltrán-Sánchez et al. (2008). This literature makes use of cause-of-death data originating with registered death certificates. Our present study has some obvious kinship with it but our framework, data source, and definitions are different. We construct a comprehensive system that encompasses transitions among health states as well as the associated mortality probabilities. We draw our data from surveys of chronic conditions rather than death registrations. Finally, and importantly, our death probabilities for people with given chronic conditions are the probabilities of dying from any cause, not just from those conditions. Nevertheless, similarity of interests invites some observations on the death registration approach.

The definition of cause-of-death based on registration data seems to offer a high degree of precision. However, in practice there are identification issues. The current version of the International Statistical Classification of Diseases (ICD-10; see World Health Organization, 2008) lists more than 2,000 codes for diseases and conditions relating to morbidity and mortality, suggesting a high degree of specificity in assigning cause of death. The reality, though, is that the choice of a specific cause is not always unambiguously obvious. The U.S. Standard Certificate of Death (National Center for Health Statistics, 2003) instructs the medical practitioner signing the certificate to enter the "IMMEDIATE CAUSE (final disease or condition resulting in death," to "Sequentially list conditions, if any, leading to the [immediate] cause," and to "enter the UNDERLYING CAUSE (disease or injury that initiated the events resulting in death) LAST" (capitalization preserved, as in the original). The physicians' handbook accompanying the death certificate observes that "causes of death on the death certificate represent a medical opinion that might vary among individual physicians" and that "a properly completed cause-of-death section provides an etiologic explanation of the order, type, and association of events resulting in death." All of this suggests some ambiguity in particular cases as to how the term "cause of death" should be uniquely interpreted – as to whether one would want to define the term narrowly, as the *immediate cause,* or more broadly, as the *underlying cause* (the *causa causans* vs. the *causa sine qua non*, to borrow terms from legal language). There is certainly a distinction between the probability of dying (of any cause) in our model and the probability of dying specifically of cancer, as in the cause-of-death literature, but the distinction is perhaps blurred a little by the foregoing.

AN AGE SEQUENCE OF TRANSITION MATRICES

Assume a sequence of ages or age groups x, x + 1, etc., to some upper limit, and (attaching now an age subscript) a corresponding sequence of probability transition matrices, P_x, P_{x+1}, etc. Assume also an initial (column) state vector v_x, the elements of which are the numbers of people in the G(n) states; in our example, with n = 3, that means nine elements, representing the healthy state, the dead state, and the seven chronic conditions states (single and multiple). With v_x given, the expected state vector at age x + 1 is then $v_{x+1} = (P_x)'v_x$, the expected state vector at x + 2 is $v_{x+2} = (P_{x+1})'v_{x+1} = (P_{x+1})'(P_x)'v_x$, and so on. Thus a complete age sequence of expected state vectors can be generated from the initial vector v_x. This provides a useful tool for tracking the implicit age history of disease and mortality in the stationary population, starting, let us say, with an initial disease-free state vector at some young age and continuing through middle age and into old age. The elements representing the chronic conditions states can be interpreted as showing the progression of disease prevalence with age in the stationary population.

The sequence of transition probability matrices makes it possible also (and perhaps more importantly) to explore the effects of changing particular probabilities to address particular questions of interest. One could ask, for example, what would be the effects of the elimination of cancer, or of diabetes, or if not complete elimination, of reducing the probability of acquiring the disease by 50 percent, perhaps, at every age. To address the elimination of cancer question, and starting with a hypothetical disease-free state vector at some young age, one would set to zero in each matrix the probability of moving from the H state to the C state, thus blocking the path from good health to cancer at every age; alternatively, one could reduce the probability at each age by half, or some other fraction. Life expectancies can be calculated, and other summary measures, based on the modified probabilities, and compared with similar calculations based on the unmodified ones. Another question of interest might be what would happen if the probability of dying for someone with cancer were to be cut in half at each age, leaving the probabilities of *acquiring* cancer untouched – that is, what would be the effect of allowing people who *have* cancer to live longer, presumably by providing more effective treatment and reducing their death rate.

The foregoing is intended to suggest possibilities for taking advantage of the type of model that we propose. It is also a preview of what we actually do in this paper, in the illustrative application below.

A DATA SET FOR APPLICATION

Our application is based on Canadian data from two sources. The first is the 2000-2002 pair of life tables for males and females (Statistics Canada, 2006a). The tables are centered on 2001, a decennial census year; the use of deaths over the three-year period 2000-2002 in the calculations by Statistics Canada was for the purpose of averaging out some of the year-to-year fluctuations. For convenience we shall refer to the tables simply as 2001 life tables, as they are commonly known.

Our second source is the Canadian Community Health Survey (CCHS), a recurrent sample survey that provides (among other things) estimates of the numbers of people with chronic health conditions, based on a long list of such conditions. (See Denton and Spencer, 2010, for the set of conditions covered and an analysis involving the full set.) The conditions that we are concerned with in the present paper are cancer, stroke/heart disease, and diabetes – more specifically, "has cancer or ever had cancer", "has heart disease or suffers from the effects of a stroke" and "has diabetes". The survey questions on which the presence of these conditions is based can reasonably be interpreted as satisfying the "irreversibility" criterion for chronic conditions in our framework.

The CCHS produces estimates, by age and sex, for ages 12 and over. In order to increase the sample size for our purposes we pooled the data from two CCHS surveys, one with data collected in 2005, known as "CCHS Cycle 3.1" (Statistics Canada, 2006b), the other with data collected in 2007 and 2008, known as "CCHS 2007-2008" (Statistics Canada, 2009). For ages 20 and over (our range of interest), microdata from these surveys are available for public use, with individual observations classified by five-year age groups from 20-24 to 75-79, plus an open-ended 80-and-over group. Working with the five-year groups, for modelling purposes, and omitting those under 20 and over 80, the combined sample size is 217,381 (virtually half and half from each survey). As a check on the consistency of the two surveys we looked at the overall proportions in each of them in the chronic conditions categories of interest and found them to be close. We also satisfied ourselves that the relevant questions in the two were similarly worded.

The individual CCHS sample observations are weighted (using weights provided by Statistics Canada) so as to make estimates based on them consistent with independent target population figures; our chronic conditions counts are thus appropriately weighted, from that point of view. However, we note that the survey target population has some exclusions: individuals living on Indian Reserves or Crown Lands, institutional residents (most importantly, for our purposes, residents of nursing homes or similar institutions), full-time members of the armed forces, and residents of certain remote regions. We have to accept those exclusions, for present purposes.

The chronic conditions data come from surveys carried out in the years 2005 and 2007/2008, whereas the life tables are centered on 2001. If accurate measurement of actual relationships in a given year were a goal the timing discrepancy would be an issue. However, that is not the case. We were concerned only to construct a reasonably realistic model of a stationary population (not an actual population) incorporating a reasonably realistic set of chronic conditions prevalence rates, and that is what we have done. The death rates on which a life table is based and the chronic conditions prevalence rates change only slowly so that the differences in timing are of no consequence for our purposes.

FROM DATA TO PROBABILITIES

The practical procedure for calculating the stationary state transition probabilities for any age group involves constructing a flow matrix for the group and then converting the flows into probabilities. The

first step is to calculate chronic conditions prevalence rates for the actual Canadian population, based on the survey data. In our example with conditions C, S, and D that means calculating prevalence rates for each of the eight single or multiple chronic conditions states by dividing the number of cases reported for each state by the age group population. (We use five-year age groups.) The next step is then to apply the prevalence rates to the corresponding life table population to obtain the number of cases that would be present in a *stationary* population with the same prevalence rates. (The stationary population for age groups is calculated from the single age life table L_x values, to use standard demography notation; see Statistics Canada, 2006a.) The calculations are thus exhaustive for the living component of the life table population; there are eight chronic conditions states (including the healthy state) and every member of the living population must be in one of them. The number of people *not* alive – the number in the dead state – is then the original number of births from the life table (an arbitrary number but typically 100,000, as in the Canadian tables) minus the surviving population in the age group.

The calculation of a flow matrix for age group x (ages 70-74, for example) requires that the foregoing procedure be applied to groups x and x+1 (70-74 and 75-79, in the example). There is then a distribution of the original birth population (100,000, say) among the nine states for each of the two age groups and the two distributions represent the row and column sums of the flow matrix: the age x distribution provides the row sums to be allocated among the elements of the matrix, the x+1 distribution provides the column sums. (See Table 1 again for the form of the matrix.) The next step is to effect the allocation and for that purpose we invoke a variation of an algorithmic method known as *iterative proportional scaling* (IPS) in the statistics literature and the *RAS method* in the literature on economic input-output modelling. Under the IPS label the first presentation seems to have been by Deming and Stephan (1940). Under the RAS label the method had its origin in work by Stone (1961, 1962) and was first explored in detail by Bacharach (1965, 1970). The method, under either label, has been applied in various contexts over the years; it is a useful and versatile procedure, and we make good use of it here. (Commenting from a statistician's point of view, Terence Speed, 2008, referred to it as "my overall favourite" algorithm.) For present purposes we shall refer to the method by its RAS label.

The RAS method goes like this. Assume a matrix (ours is square, though that need not be the case) with unknown elements but known marginal (row, column) totals – true totals, let us call them. Nonnegative estimates of the elements of the matrix are supplied and those have their own marginal totals, which in general will be different from the true ones. The problem is to adjust the initial estimated elements so as to produce a matrix that conforms exactly with the true totals. The adjustment algorithm is iterative and simple: (1) adjust each element in each row *pro rata* so that the elements sum to the true row totals; (2) now adjust the (previously adjusted) elements in each column *pro rata* so that they sum to the true column totals; (3) now do it all over for the rows, then for the columns, then for the rows again, and so on. As long as there are no inconsistencies in the original estimates (a row of zeros that must be adjusted, impossibly, to a positive row total, for example) the matrix will converge (with any specified degree of accuracy) to a final form that satisfies both row and column adding-up restrictions, after a finite number of iterations.

We adapt the procedure to our situation. The stationary population marginal totals are the true totals – the age group x totals for the rows, the age group x+1 totals for the columns. Our flow matrix is a 9x9 matrix with 81 elements to be derived. The row/column adding-up requirements provide 17 restrictions that must be satisfied. (The row totals and the column totals must each add to the same overall total so one of the 18 restrictions from that source is redundant.) In addition, there are 81-36=45 zero (inadmissibility) restrictions. Thus in total there are 62 equality restrictions that the elements of the matrix must satisfy. Also, the admissible elements of the matrix must be positive so there are 36 inequality restrictions of the form fij > 0 that must be satisfied too, making an overall total of 98 restrictions. Application of the RAS method is what allows us to derive values for the 81 elements of the matrix, given all of the restrictions, but for that we need a matrix to serve as an initial approximation and to set in motion the iterative procedure. If there were no zero restrictions on some of the elements the assumption of independence among row and column effects (if we were willing to make that assumption) would be a candidate and would produce a matrix that satisfied the adding-up restrictions directly, without any need for iteration; that is, the elements would be calculated as $f_{ij} = (r_i s_j)T$, where T is the overall total (the living plus dead population), r_i is the row i total as a proportion of T, and s_j is the column j total as a proportion of T. The zero restrictions make the assumption of independence untenable, though, and so we move away from it by writing instead $f_{ij} = (r_i s_j)(T)z_{ij}$ for the initial values of the matrix, where $z_{ij} = 1$ if a nonzero (positive) value is admissible for the i,j element of the matrix, $z_{ij} = 0$ if it is inadmissible. With that change the adding-up restrictions are no longer satisfied directly, and so the RAS procedure is invoked and the initial matrix is adjusted iteratively until consistency with the true marginal totals is achieved. All of the 98 restrictions, equality and inequality, are then satisfied.

Once the flow matrix F has been derived in this way the transition probability matrix P can be calculated in a straightforward manner, as described above. Table 2 shows, for illustration, the P matrix for the 70-74 age group – the probability matrix for transitions between ages 70-74 and ages 75-79, that is. A separate version of the matrix is shown for each of males and females. We have calculated similar matrices for all age groups from 20-24 to 65-69. (See Appendix Tables A1 to A11.)

Some observations on Table 2 before moving on. First, at a general level, and in light of all the foregoing, the probability matrices represent patterns of movement within an artificial population but they are grounded in real survey and demographic data. The flow matrices on which they are based satisfy the adding-up, irreversibility, and positivity restrictions derived from the chronic conditions survey data, as they must, by construction. They satisfy also the requirement that the overall age-group-specific death probabilities must be consistent with life table probabilities, again by construction. At a more specific level, a few characteristics of the matrices may be noted: (1) the death probability for someone with two chronic conditions is always much higher than the single-condition probabilities (compare the probabilities for CS with those for C or S alone) and the probability for someone unlucky enough to have all three conditions is much higher still, as one would expect; (2) the death probabilities are higher for males than for females (consistent with overall life table probabilities), with the single exception of the probability for the CD state (and even there, the probability of *entering* that high mortality state from any other possible state is greater for males); (3) the probability of remaining in good health (staying in H) is uniformly higher for females. Overall, the probability matrices seem to pass

a “reasonableness” check, both for the 70-74 age group in Table 2 and the other age groups for which we have constructed similar matrices, and which we have examined in detail.

SIMULATING THE SEQUENCE OF STATE VECTORS

The calculated set of (male or female) transition probability matrices makes it possible to simulate, recursively, the state vectors for successive age groups, starting from an assumed initial vector. We set the initial population at 100 for ages 20-24 with all members of the population in the H state so that the initial vector is (100, 0, 0, … , 0). (Specifying the initial vector in that form allows us the convenience of being able to interpret the elements of subsequent vectors as percentages of the original population.) We then move the vector forward to ages 25-29 by applying the 20-24 transition probabilities (as described previously), then to ages 30-34 by applying the 25-29 probabilities, and so on. The vectors obtained in this way are shown, for selected age groups, in Table 3.

The vector sequences in the table show that the percentage of males in good health (no C, S, or D) falls from 100 to 93.71 by ages 40-44, and then declines steadily to 37.43, by ages 70-74. For females the percentage is almost the same as for males at ages 40-44 (93.24) but then declines more slowly; by ages 70-74, 53.10 percent of the initial population of women are in the H state, compared with the 37.43 percentage for men.

The percentage survival rate (100 minus the percentage in the dead state) is higher for women (as we know it should be from the life tables), falling only to 83.54 percent by ages 70-74 compared with 73.15 for men. In terms of the distribution of chronic conditions, women have a higher proportion with cancer than men at all ages after the initial one (but especially at ages below 70-74, attributable presumably to breast cancer) and lower proportions in the stroke/heart disease and diabetes categories.

Percentage distributions generally similar to the state vectors in Table 3 could be calculated directly from the underlying survey data, adjusted for survival rates. Checks indicate that the simulated percentages are close to direct survey-based percentages, as indeed they should be, given that the prevalence rates used in constructing the transition probability matrices come from the same source. If actual percentage distributions (state vectors) were all that were required the whole process of developing the probability matrices might be less rewarding. However, the probabilities are of interest in themselves. Moreover, they permit alternative simulation experiments – “what if” experiments involving changing particular probabilities.

EXPLORATION: CHANGING THE PROBABILITIES

We alter the transition probabilities now and rerun the simulations of state vectors. The altered probabilities represent nine scenarios (Sc), as we shall call them, of three different types. In the first type, the probability of developing a particular chronic condition is set to zero at all ages; the condition is thus eliminated by blocking entry. In the second type, the probability of developing a chronic

condition is reduced by half at every age. In the third, the probability of developing a condition is unchanged but the probability of dying for someone with the condition is reduced by half at every age. Specifically the scenarios are as follows:

Sc0 – baseline scenario: no change in any of the probabilities

ScC1 – probability of developing cancer set to zero at every age (cancer eliminated completely)

ScC2 – probability of developing cancer reduced by half at every age

ScC3 – probability of dying for someone with cancer reduced by half at every age

ScS1 – probability of developing heart disease or having a stroke set to zero at every age (stroke/heart disease eliminated completely)

ScS2 – probability of developing heart disease or having a stroke reduced by half at every age

ScS3 – probability of dying for someone with heart disease or having a stroke reduced by half at every age

ScD1 – probability of developing diabetes set to zero at every age (diabetes eliminated completely)

ScD2 – probability of developing diabetes reduced by half at every age

ScD3 – probability of dying for someone with diabetes reduced by half at every age

The adjustments to eliminate a chronic condition entirely are straightforward. To eliminate cancer, for example, the probability of entry into any state with a C label (C, CS, CD, CSD) is set to zero and the original probabilities are reassigned (the probabilities must still sum to one in every row). C is merged with H (the original C and H probabilities are added together, that is, since no one now is able to move from H to C), CS is merged with S, CD with D, and CSD with SD, in every relevant row, leaving X unchanged. In effect, the label C disappears from the matrix.

The adjustments to reduce the chronic conditions entry probabilities by half are similar, except that half of the entry probability for a C-label state remains while the other half is merged, as above. (Half of the probability of moving from H to C is reassigned to H, the other half remains; half of the probability of moving from S to CS is reassigned to the S-to-S probability, the other half remains as it was; and so on.)

The adjustments involving the death probabilities are trickier. Reducing the probability for someone in the C state is straightforward, for example – the probability of moving from C to CX in the C row of the matrix is simply now half of what it was originally and the difference is reassigned *pro rata* to the other probabilities in that row. But how to alter the probabilities in a row such as the CD row requires some assumption. Presumably the death probability for someone with both cancer and diabetes should be lowered if the death probability for someone with cancer alone is lowered, but by how much? Our working assumption is that the new death probability for someone in the CD state should be adjusted by a factor equal to the death probability for D alone plus the reduced death probability for C alone,

divided by the original sum of the same two probabilities. That is an arbitrary assumption but it takes account of the relationship between the C and D probabilities in adjusting the death probability for the combined CD state. The CD death probability having been thus reduced, the difference from the original probability is then reassigned to the other nonzero probabilities in the CD row. Similar assumptions are made for the other combined-state probabilities in the matrix.

INTERPRETING THE SCENARIO SIMULATIONS

The simulated state vectors corresponding to the altered probability scenarios are shown in Table 4 for the 70-74 male and female age groups, generated, as before, from an initial 100 percent healthy age 20-24 vector. Eliminating cancer increases markedly the proportion of 70-74-year-olds in the healthy state, as one would expect, and raises the proportion of survivors – from 73.15 to 79.61 for males, 83.54 to 90.18 for females. But with more survivors, free of cancer, but eligible for the other chronic conditions, the stroke/heart disease and diabetes proportions increase, both separately and in combination. Reducing the cancer entry probability by only half at every age (ScC2) has similar but correspondingly smaller effects on the state vectors. Eliminating or reducing the entry probabilities for stroke/heart disease and diabetes (ScS1, ScS2, ScD1, ScD2) increases the proportion in the healthy state and the proportion of survivors in a similar way, but with some differences in size of effect, and increases also the proportions with the other chronic conditions. Interestingly, though, cutting the death probability by half for a particular chronic condition (ScC3, ScS3, ScD3) has a smaller effect than cutting the entry probability by half. Cutting the cancer entry probability by half at every age, for example, increases the ages 70-74 survival proportion from 73.15 to 76.28 for males but reducing the death probability at every age by half increases it only to 75.32. For females the corresponding changes are from 83.54 to 86.73 with the entry probability reductions, but only to 85.56 with the death probability reductions.

These results reflect the complex system of interactions among the different chronic conditions and mortality probabilities. Someone living longer because of a reduced probability of developing one of the conditions has an increased probability of developing one or both of the other conditions over his/her lifetime, with concomitant changes in death probabilities. An advantage of modelling different chronic conditions and mortality rates together in a single integrated age-dynamic system is that it brings to light and takes account of these interactions. (We refer here to the system as age-dynamic because it allows the effects of state changes in one age group to carry forward to subsequent ages as the group grows older. From the point of view of the entire population, though, the system is stationary: the probabilities at any given age are invariant with time.) That there are such interactions is not a novel idea. It is well known in the literature on modelling the effects of eliminating cancer or other particular diseases. Our contribution is to make it explicit in an integrated framework, to show how the interactions play out over a lifetime, and to show how the associated “what if” probabilities can be derived by experimenting with a model constructed from life table and chronic conditions survey data.

EFFECTS ON LIFE EXPECTANCY

In the 2001 life tables (and others like them) life expectancy (the average number of years of life remaining at any given age) is calculated from death rates by single years of age up to the age at which it is assumed that there are no more survivors. The latter is taken to be 110 for practical purposes in the 2001 tables and we make the same assumption. To calculate life expectancies for our purposes, though, there are two problems. The first is that we work with age groups rather than single ages; to deal with that we treat the age path of state vectors as a step function, with changes only at five-year intervals. The second problem is that our chronic conditions data base provides five-year age group data only up to 75-79; to deal with that requires making some assumptions that allow us to calculate five-year state vectors over the range 80-84 to 105-109.

Our procedure is as follows. Given a total population of 100, as in the experiments just discussed, we have our calculated state vector at ages 75-79 (with elements summing to 100) and we know that the ultimate state vector, for the age group 110-114, must be (0, 0, …, 0, 100). We also know (from the life table) the path of survivors between the two age groups – the L_x values. What we do then is to use the L_x series to interpolate between the 75-79 state vector at the lower end and the 110-114 vector at the upper end. That preserves the adding-up (to 100) requirement for each vector and means that the individual survivor components of the state vector follow age paths consistent with the overall life table survivor path. It gives us only an approximation to the series of state vectors after 75-79 but it allows us to calculate life expectancies over the whole age range and to compare those expectancies with the ones in the life table, as a check. Given that our expectancies are sufficiently close to the life table ones for the baseline (Sc0) simulations we can then see how they change when the simulations are carried out for the other (experimental) scenarios. Each scenario produces a different 75-79 state vector, and hence (with a new round of interpolation) a different series of vectors for ages 80-84 and above.

The path of the state vectors being represented by a step function, the number of people alive at age 20 is the same as the number alive at each age in the 20-24 age group (namely, 100). Given the sequence of survivors provided by the state vectors we can then calculate the life expectancy for a 20-year-old. Similarly, we can do the same calculation for a 65-year-old. The calculations for both are shown in Table 5 for the Sc0 scenario and for each of the experimental ones. Also shown are the percentages of the population surviving to ages 60-64 and 70-74.

Life expectancy at age 20 is 58.53 years for males, according to our calculation, about four-fifths of a year higher than the 2001 life table calculation. For females, our calculation is 63.25, about three-fifths of a year higher than the life table calculation. The differences at age 65 are roughly similar to those at age 20. Treating the path of the state vectors as a step (rather than continuous) function will overstate a little the number of years lived within a five-year interval, especially at older ages, and hence overstate the calculated life expectancies. Also, we assume, in the simulations, an initial population at age 20 that is entirely in the healthy state whereas the actual population on which the life table probabilities are based would have a small proportion in the chronic health conditions states, and that too would tend to make our life expectancies slightly higher than the life table ones. Small differences from the life table values are therefore to be expected, even though the overall five-year death probabilities are consistent

with those in the life tables. But the expectancies themselves are not of prime interest; it is the changes in expectancies that we are interested in when the chronic conditions entry and death probabilities are modified.

Life expectancies are always higher in the experimental scenarios than in the baseline scenario, as one would of course expect. The differences might be regarded as generally modest but that should come as no surprise; it has long been recognized that elimination or mortality reduction for one disease leaves the beneficiaries open to death from others, and that the offsetting effects can be much greater than casual reflection might suggest. The largest increase for males at age 20 is about 2.8 years, in the ScD1 scenario, with diabetes eliminated. For females, the largest difference is about 2.1 years, again with the elimination of diabetes. (We remind the reader once more that all results are based on the probabilities of dying for people who have particular conditions, not the probabilities of dying specifically from those conditions.)

SOME IMPLICATIONS FOR HEALTH CARE UTILIZATION

The survey that provides our chronic conditions data provides also some information on four types of health care services – the annual numbers of overnight stays in hospital, family doctor consultations, eye specialist consultations, and other medical doctor consultations. The numbers can be converted to age-group-specific per capita utilization ratios for the population in different chronic conditions categories and incorporated into our framework. We apply the ratios to each of the eight living-population states and aggregate the results to obtain overall indexes for the four types of health care services, with the Sc0 scenario index set at a base value of 100.0. Table 6 shows how the indexes differ from that value in the other scenarios.

We note a few of the features of the table and offer some interpretation. First, in general, there are two types of effects. Eliminating or reducing the incidence of a chronic condition results in less use of the particular services required for dealing with that condition. Thus, eliminating or reducing the incidence of cancer results in a lowering of the population's aggregate number of nights in hospital and the aggregate use of the services of relevant medical specialists (caught up in the "other medical doctor" category). That is one type of effect. The other type is the effect of simply prolonging lives, as reflected most prominently in the ScC3, ScS3, and ScD3 scenarios: cutting the death probabilities in half for a particular chronic condition means more people living, and using a range of health care services (like the rest of the population) at any given time. More living elderly people means more use of eye specialist services, for example. These two effects do not operate independently, of course; reducing the probability of getting cancer would no doubt have both of them, although the first one seems to dominate. The biggest effects of all in the table come from the elimination or reduction in the stroke/heart condition category: hospital utilization declines by 17 or 18 percent in ScS1 and 8 percent in ScS2, for both males and females.

The foregoing is our interpretation of the results in table 6. We do not want to read too much into them; they represent a high level of aggregation and a simplification of what is no doubt a complex set

of interactions within the health care system. However, they do serve to draw attention to the two types of effects that one might expect from improvements in treatment and mortality reduction – the direct effects on the utilization of particular services for a given condition and the indirect effects that come about simply from having more people living longer lives.

CONCLUSION

We hope that a reader will find the results of our "what if" simulation experiments interesting. Beyond that, our aim has been to demonstrate a way in which the age dynamics of chronic conditions can be explored, with possible applications in other contexts – with other survey data, with other selections of the conditions to be investigated. As we have shown, the size of the transition probability matrix increases rapidly as the number of chronic conditions is increased but the addition of conditions beyond our set of three would provide a basis for richer and more comprehensive experimentation. The chosen conditions would have to be deemed irreversible, of course. That may depend on the ways in which questions are posed and suggests the possibility that those with responsibility for future chronic conditions surveys might take the matter into consideration, perhaps by modifying questions used previously, perhaps by adding new ones. (Recall the important distinction between the possibly reversible "do you have cancer?" type of question and the clearly irreversible one, "have you ever been diagnosed with cancer?".) Changes of this kind would require only modest alterations to existing questionnaires and could be implemented easily. Surveys of chronic conditions provide valuable information about prevalence rates; we would like to think that we have shown a way in which such surveys could be made even more valuable by allowing the calculation of the transition probabilities that define the chronic conditions age dynamic process.

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Table 1: Admissible (√) and Inadmissible (0) Elements of the Flow Matrix

State at age x	State at age x+1								
	H	C	S	D	CS	CD	SD	CSD	X
H	√	√	√	√	√	√	√	√	√
C	0	√	0	0	√	√	0	√	√
S	0	0	√	0	√	0	√	√	√
D	0	0	0	√	0	√	√	√	√
CS	0	0	0	0	√	0	0	√	√
CD	0	0	0	0	0	√	0	√	√
SD	0	0	0	0	0	0	√	√	√
CSD	0	0	0	0	0	0	0	√	√
X	0	0	0	0	0	0	0	0	√

Table 2: State Transition Probabilities, Age Group 70-74: Base Scenario (Sc0)

State, age group 70-74	State, age group 75-79								
	H	C	S	D	CS	CD	SD	CSD	X
Males									
H	.7445	.0671	.0857	.0458	.0117	.0076	.0101	.0014	.0262
C	.0000	.5888	.0000	.0000	.1027	.0664	.0000	.0119	.2302
S	.0000	.0000	.6342	.0000	.0866	.0000	.0749	.0100	.1942
D	.0000	.0000	.0000	.5029	.0000	.0831	.1111	.0149	.2880
CS	.0000	.0000	.0000	.0000	.2978	.0000	.0000	.0345	.6677
CD	.0000	.0000	.0000	.0000	.0000	.2153	.0000	.0386	.7461
SD	.0000	.0000	.0000	.0000	.0000	.0000	.2684	.0360	.6957
CSD	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0491	.9509
X	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	1.0000
Females									
H	.7871	.0470	.0901	.0392	.0076	.0026	.0095	.0015	.0155
C	.0000	.6337	.0000	.0000	.1023	.0354	.0000	.0196	.2091
S	.0000	.0000	.7259	.0000	.0611	.0000	.0763	.0117	.1250
D	.0000	.0000	.0000	.5742	.0000	.0385	.1387	.0213	.2273
CS	.0000	.0000	.0000	.0000	.3090	.0000	.0000	.0592	.6318
CD	.0000	.0000	.0000	.0000	.0000	.1342	.0000	.0742	.7916
SD	.0000	.0000	.0000	.0000	.0000	.0000	.3581	.0550	.5869
CSD	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0857	.9143
X	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	1.0000

Table 3: State Vectors, Selected Age Groups: Base Scenario (Sc0)

State	Age group				
	20-24	40-44	50-54	60-64	70-74
Males					
H	100.00	93.71	82.67	61.80	37.43
C	0.00	1.10	3.02	6.93	9.20
S	0.00	1.39	3.92	7.38	10.04
D	0.00	2.40	5.30	8.31	7.92
CS	0.00	0.10	0.14	0.94	2.83
CD	0.00	0.03	0.31	0.89	1.42
SD	0.00	0.21	1.01	2.98	3.38
CSD	0.00	0.01	0.04	0.26	0.94
X	0.00	1.04	3.59	10.51	26.85
Total	100.00	100.00	100.00	100.00	100.00
Females					
H	100.00	93.24	83.17	68.96	53.10
C	0.00	2.98	7.18	9.31	9.79
S	0.00	1.24	2.34	5.10	7.85
D	0.00	1.65	3.93	6.46	6.85
CS	0.00	0.04	0.31	0.79	1.66
CD	0.00	0.10	0.38	0.90	1.18
SD	0.00	0.19	0.57	1.66	2.53
CSD	0.00	0.01	0.06	0.56	0.58
X	0.00	0.54	2.05	6.24	16.46
Total	100.00	100.00	100.00	100.00	100.00

Table 4: State Vectors, Ages 20-24 and 70-74: Alternative Scenarios

State	Ages 20-24	Ages 70-74 (alternative scenarios)									
	(all scenarios)	Sc0	ScC1	ScC2	ScC3	ScS1	ScS2	ScS3	ScD1	ScD2	ScD3
Males											
H	100.00	37.43	49.70	43.22	37.43	51.62	44.07	37.43	50.33	43.48	37.43
C	0.00	9.20	0.00	4.90	10.32	13.58	11.22	9.20	12.56	10.77	9.20
S	0.00	10.04	14.22	11.99	10.04	0.00	5.41	11.10	15.97	12.71	10.04
D	0.00	7.92	10.70	9.23	7.92	13.71	10.49	7.92	0.00	4.27	9.26
CS	0.00	2.83	0.00	1.53	3.35	0.00	1.55	3.30	4.60	3.62	2.83
CD	0.00	1.42	0.00	0.77	1.72	2.74	2.00	1.42	0.00	0.77	1.83
SD	0.00	3.38	5.00	4.13	3.38	0.00	1.92	4.19	0.00	1.89	4.55
CSD	0.00	0.94	0.00	0.52	1.17	0.00	0.54	1.20	0.00	0.53	1.35
X	0.00	26.85	20.39	23.72	24.68	18.35	22.81	24.25	16.54	22.00	23.51
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Females											
H	100.00	53.10	66.80	59.61	53.10	63.69	58.20	53.10	63.83	58.25	53.10
C	0.00	9.79	0.00	5.17	10.92	12.75	11.19	9.79	12.49	11.07	9.79
S	0.00	7.85	10.52	9.10	7.85	0.00	4.10	8.39	11.19	9.39	7.85
D	0.00	6.85	9.18	7.94	6.85	10.41	8.48	6.85	0.00	3.59	7.61
CS	0.00	1.66	0.00	0.89	2.06	0.00	0.89	1.94	2.55	2.06	1.66
CD	0.00	1.18	0.00	0.64	1.49	1.99	1.55	1.18	0.00	0.63	1.50
SD	0.00	2.53	3.67	3.06	2.53	0.00	1.38	2.94	0.00	1.36	3.12
CSD	0.00	0.58	0.00	0.32	0.77	0.00	0.32	0.70	0.00	0.32	0.77
X	0.00	16.46	9.82	13.27	14.44	11.16	13.90	15.12	9.95	13.33	14.61
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 5: Longevity Indicators: Alternative Scenarios

Indicator	Alternative Scenarios									
	Sc0	ScC1	ScC2	ScC3	ScS1	ScS2	ScS3	ScD1	ScD2	ScD3
Males										
Life expectancy										
-age 20	58.53	60.49	59.47	59.23	60.92	59.66	59.28	61.36	59.87	59.46
-age 65	17.78	18.72	18.23	18.12	18.98	18.35	18.17	19.15	18.43	18.23
% survivors										
-ages 60-64	89.49	92.21	90.83	90.44	92.93	91.17	90.60	93.61	91.50	90.92
-ages 70-74	73.15	79.61	76.28	75.32	81.65	77.19	75.75	83.46	78.04	76.49
Females										
Life expectancy										
-age 20	63.25	65.38	64.27	63.93	64.92	64.06	63.70	65.33	64.25	63.86
-age 65	21.11	22.13	21.60	21.45	21.85	21.47	21.31	22.12	21.60	21.43
% survivors										
-ages 60-64	93.76	96.37	95.03	94.65	95.81	94.77	94.34	96.15	94.93	94.50
-ages 70-74	83.54	90.18	86.73	85.56	88.84	86.10	84.88	90.05	86.67	85.39

Table 6: Utilization of Hospital and Medical Services: Alternative Scenarios
(indexes: Sc0 = 100.0)

Service	Alternative scenarios									
	Sc0	ScC1	ScC2	ScC3	ScS1	ScS2	ScS3	ScD1	ScD2	ScD3
Males										
-hospital	100.0	94.6	97.5	105.0	82.1	91.9	106.4	105.0	102.4	106.2
-family doctor	100.0	103.2	101.5	102.1	100.4	100.2	102.7	102.3	101.1	103.3
-eye specialist	100.0	104.5	102.2	102.2	106.3	103.0	102.4	102.7	101.3	103.4
-other medical doctor	100.0	91.5	96.0	103.5	97.1	98.7	103.0	103.9	101.8	103.2
Females										
-hospital	100.0	97.5	98.8	104.0	82.7	92.1	103.7	97.6	98.9	104.5
-family doctor	100.0	102.6	101.2	101.5	98.9	99.5	101.2	100.7	100.3	101.6
-eye specialist	100.0	104.3	102.1	101.8	102.6	101.3	101.2	102.7	101.3	101.7
-other medical doctor	100.0	95.0	97.6	101.7	97.1	98.6	101.1	101.3	100.6	101.2

Note: Hospital services are based on annual numbers of overnight stays; other services are based on annual numbers of consultations.

APPENDIX

TABLES

Table A1: State Transition Probabilities, Age Group 20-24: Basic Scenario (Sc0)

State, age group, 20-24	State, age group 25-29								
	H	C	S	D	CS	CD	SD	CSD	X
Males									
H	0.9946	0.0016	0.0009	0.0026	0.0000	0.0000	0.0000	0.0000	0.0003
C	0.0000	0.8256	0.0000	0.0000	0.0001	0.0002	0.0000	0.0001	0.1740
S	0.0000	0.0000	0.7142	0.0000	0.0002	0.0000	0.0161	0.0001	0.2694
D	0.0000	0.0000	0.0000	0.8790	0.0000	0.0001	0.0068	0.0001	0.1141
CS	0.0000	0.0000	0.0000	0.0000	0.0006	0.0000	0.0000	0.0005	0.9989
CD	0.0000	0.0000	0.0000	0.0000	0.0000	0.0010	0.0000	0.0005	0.9985
SD	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0563	0.0005	0.9433
CSD	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0005	0.9995
X	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000
Females									
H	0.9911	0.0017	0.0030	0.0041	0.0000	0.0000	0.0000	0.0000	0.0001
C	0.0000	0.9243	0.0000	0.0000	0.0015	0.0093	0.0000	0.0001	0.0648
S	0.0000	0.0000	0.9611	0.0000	0.0009	0.0000	0.0001	0.0000	0.0379
D	0.0000	0.0000	0.0000	0.9673	0.0000	0.0041	0.0001	0.0000	0.0285
CS	0.0000	0.0000	0.0000	0.0000	0.0222	0.0000	0.0000	0.0012	0.9766
CD	0.0000	0.0000	0.0000	0.0000	0.0000	0.1257	0.0000	0.0011	0.8732
SD	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0030	0.0012	0.9958
CSD	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0012	0.9988
X	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000

Table A2: State Transition Probabilities, Age Group 25-29: Basic Scenario (Sc0)

State, age group, 25-29	State, age group 30-34								
	H	C	S	D	CS	CD	SD	CSD	X
Males									
H	0.9915	0.0037	0.0022	0.0019	0.0001	0.0000	0.0000	0.0000	0.0005
C	0.0000	0.8460	0.0000	0.0000	0.0289	0.0109	0.0000	0.0001	0.1142
S	0.0000	0.0000	0.7681	0.0000	0.0445	0.0000	0.0113	0.0001	0.1760
D	0.0000	0.0000	0.0000	0.7646	0.0000	0.0193	0.0130	0.0001	0.2031
CS	0.0000	0.0000	0.0000	0.0000	0.2017	0.0000	0.0000	0.0004	0.7979
CD	0.0000	0.0000	0.0000	0.0000	0.0000	0.0868	0.0000	0.0004	0.9128
SD	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0601	0.0004	0.9395
CSD	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0005	0.9995
X	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000
Females									
H	0.9872	0.0097	0.0001	0.0029	0.0000	0.0001	0.0000	0.0000	0.0000
C	0.0000	0.9908	0.0000	0.0000	0.0001	0.0072	0.0000	0.0000	0.0018
S	0.0000	0.0000	0.7037	0.0000	0.0137	0.0000	0.0512	0.0039	0.2276
D	0.0000	0.0000	0.0000	0.9693	0.0000	0.0233	0.0013	0.0001	0.0060
CS	0.0000	0.0000	0.0000	0.0000	0.0557	0.0000	0.0000	0.0160	0.9282
CD	0.0000	0.0000	0.0000	0.0000	0.0000	0.7934	0.0000	0.0035	0.2031
SD	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1810	0.0139	0.8051
CSD	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0170	0.9830
X	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000

Table A3: State Transition Probabilities, Age Group 30-34: Basic Scenario (Sc0)

State, age group, 30-34	State, age group 35-39								
	H	C	S	D	CS	CD	SD	CSD	X
Males									
H	0.9803	0.0052	0.0043	0.0090	0.0000	0.0000	0.0003	0.0000	0.0010
C	0.0000	0.8337	0.0000	0.0000	0.0001	0.0050	0.0000	0.0038	0.1575
S	0.0000	0.0000	0.7693	0.0000	0.0001	0.0000	0.0494	0.0042	0.1770
D	0.0000	0.0000	0.0000	0.8727	0.0000	0.0030	0.0266	0.0023	0.0954
CS	0.0000	0.0000	0.0000	0.0000	0.0005	0.0000	0.0000	0.0233	0.9762
CD	0.0000	0.0000	0.0000	0.0000	0.0000	0.0299	0.0000	0.0226	0.9474
SD	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.2142	0.0183	0.7674
CSD	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0233	0.9767
X	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000
Females									
H	0.9825	0.0086	0.0038	0.0043	0.0002	0.0001	0.0001	0.0000	0.0003
C	0.0000	0.9333	0.0000	0.0000	0.0220	0.0099	0.0000	0.0020	0.0328
S	0.0000	0.0000	0.8553	0.0000	0.0453	0.0000	0.0276	0.0042	0.0676
D	0.0000	0.0000	0.0000	0.8885	0.0000	0.0190	0.0257	0.0039	0.0629
CS	0.0000	0.0000	0.0000	0.0000	0.3870	0.0000	0.0000	0.0356	0.5774
CD	0.0000	0.0000	0.0000	0.0000	0.0000	0.2215	0.0000	0.0452	0.7333
SD	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.2780	0.0419	0.6801
CSD	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0580	0.9420
X	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000

Table A4: State Transition Probabilities, Age Group 35-39: Basic Scenario (Sc0)

State, age group, 35-39	State, age group 40-44								
	H	C	S	D	CS	CD	SD	CSD	X
Males									
H	0.9694	0.0045	0.0092	0.0141	0.0004	0.0001	0.0009	0.0000	0.0014
C	0.0000	0.7071	0.0000	0.0000	0.0547	0.0151	0.0000	0.0019	0.2211
S	0.0000	0.0000	0.7763	0.0000	0.0297	0.0000	0.0730	0.0011	0.1199
D	0.0000	0.0000	0.0000	0.8547	0.0000	0.0059	0.0525	0.0008	0.0862
CS	0.0000	0.0000	0.0000	0.0000	0.1970	0.0000	0.0000	0.0070	0.7960
CD	0.0000	0.0000	0.0000	0.0000	0.0000	0.0633	0.0000	0.0082	0.9285
SD	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.3764	0.0054	0.6182
CSD	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0087	0.9913
X	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000
Females									
H	0.9700	0.0126	0.0079	0.0081	0.0001	0.0002	0.0006	0.0000	0.0005
C	0.0000	0.9346	0.0000	0.0000	0.0076	0.0186	0.0000	0.0017	0.0375
S	0.0000	0.0000	0.8617	0.0000	0.0112	0.0000	0.0694	0.0025	0.0551
D	0.0000	0.0000	0.0000	0.8514	0.0000	0.0263	0.0668	0.0025	0.0531
CS	0.0000	0.0000	0.0000	0.0000	0.1624	0.0000	0.0000	0.0370	0.8006
CD	0.0000	0.0000	0.0000	0.0000	0.0000	0.3213	0.0000	0.0300	0.6487
SD	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.5463	0.0200	0.4337
CSD	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0442	0.9558
X	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000

Table A5: State Transition Probabilities, Age Group 40-44: Basic Scenario (Sc0)

State, age group, 40-44	State, age group 45-49								
	H	C	S	D	CS	CD	SD	CSD	X
Males									
H	0.9676	0.0088	0.0095	0.0117	0.0001	0.0003	0.0005	0.0000	0.0014
C	0.0000	0.8291	0.0000	0.0000	0.0089	0.0309	0.0000	0.0018	0.1293
S	0.0000	0.0000	0.8247	0.0000	0.0082	0.0000	0.0462	0.0016	0.1193
D	0.0000	0.0000	0.0000	0.8379	0.0000	0.0237	0.0383	0.0014	0.0989
CS	0.0000	0.0000	0.0000	0.0000	0.0637	0.0000	0.0000	0.0127	0.9236
CD	0.0000	0.0000	0.0000	0.0000	0.0000	0.1910	0.0000	0.0110	0.7980
SD	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.2763	0.0098	0.7139
CSD	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0136	0.9864
X	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000
Females									
H	0.9563	0.0225	0.0067	0.0124	0.0003	0.0004	0.0006	0.0000	0.0007
C	0.0000	0.9382	0.0000	0.0000	0.0138	0.0167	0.0000	0.0012	0.0300
S	0.0000	0.0000	0.7995	0.0000	0.0397	0.0000	0.0710	0.0036	0.0863
D	0.0000	0.0000	0.0000	0.8763	0.0000	0.0284	0.0420	0.0021	0.0511
CS	0.0000	0.0000	0.0000	0.0000	0.3063	0.0000	0.0000	0.0276	0.6661
CD	0.0000	0.0000	0.0000	0.0000	0.0000	0.3485	0.0000	0.0259	0.6256
SD	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.4415	0.0222	0.5363
CSD	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0397	0.9603
X	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000

Table A6: State Transition Probabilities, Age Group 45-49: Basic Scenario (Sc0)

State, age group, 45-49	State, age group 50-54								
	H	C	S	D	CS	CD	SD	CSD	X
Males									
H	0.9118	0.0190	0.0266	0.0322	0.0006	0.0012	0.0040	0.0001	0.0045
C	0.0000	0.7458	0.0000	0.0000	0.0250	0.0474	0.0000	0.0045	0.1774
S	0.0000	0.0000	0.7416	0.0000	0.0178	0.0000	0.1114	0.0032	0.1261
D	0.0000	0.0000	0.0000	0.7658	0.0000	0.0287	0.0950	0.0027	0.1077
CS	0.0000	0.0000	0.0000	0.0000	0.1208	0.0000	0.0000	0.0217	0.8575
CD	0.0000	0.0000	0.0000	0.0000	0.0000	0.2066	0.0000	0.0196	0.7738
SD	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.4627	0.0132	0.5241
CSD	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0247	0.9753
X	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000
Females									
H	0.9328	0.0307	0.0123	0.0196	0.0008	0.0009	0.0014	0.0001	0.0014
C	0.0000	0.9066	0.0000	0.0000	0.0233	0.0270	0.0000	0.0024	0.0408
S	0.0000	0.0000	0.7709	0.0000	0.0494	0.0000	0.0881	0.0050	0.0865
D	0.0000	0.0000	0.0000	0.8385	0.0000	0.0391	0.0600	0.0034	0.0589
CS	0.0000	0.0000	0.0000	0.0000	0.3504	0.0000	0.0000	0.0358	0.6138
CD	0.0000	0.0000	0.0000	0.0000	0.0000	0.3850	0.0000	0.0339	0.5811
SD	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.4904	0.0281	0.4815
CSD	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0551	0.9449
X	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000

Table A7: State Transition Probabilities, Age Group 50-54: Basic Scenario (Sc0)

State, age group, 50-54	State, age group 55-59								
	H	C	S	D	CS	CD	SD	CSD	X
Males									
H	0.8611	0.0357	0.0361	0.0484	0.0025	0.0019	0.0078	0.0003	0.0061
C	0.0000	0.7674	0.0000	0.0000	0.0531	0.0413	0.0000	0.0075	0.1307
S	0.0000	0.0000	0.6835	0.0000	0.0467	0.0000	0.1482	0.0066	0.1151
D	0.0000	0.0000	0.0000	0.7497	0.0000	0.0298	0.1211	0.0054	0.0941
CS	0.0000	0.0000	0.0000	0.0000	0.2775	0.0000	0.0000	0.0390	0.6835
CD	0.0000	0.0000	0.0000	0.0000	0.0000	0.2303	0.0000	0.0416	0.7281
SD	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.5492	0.0243	0.4265
CSD	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0540	0.9460
X	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000
Females									
H	0.9214	0.0249	0.0167	0.0315	0.0010	0.0011	0.0018	0.0001	0.0016
C	0.0000	0.8681	0.0000	0.0000	0.0337	0.0389	0.0000	0.0035	0.0558
S	0.0000	0.0000	0.7904	0.0000	0.0458	0.0000	0.0830	0.0048	0.0760
D	0.0000	0.0000	0.0000	0.8731	0.0000	0.0310	0.0486	0.0028	0.0445
CS	0.0000	0.0000	0.0000	0.0000	0.3618	0.0000	0.0000	0.0381	0.6001
CD	0.0000	0.0000	0.0000	0.0000	0.0000	0.3955	0.0000	0.0361	0.5684
SD	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.5065	0.0295	0.4641
CSD	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0597	0.9403
X	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000

Table A8: State Transition Probabilities, Age Group 55-59: Basic Scenario (Sc0)

State, age group, 55-59	State, age group 60-64								
	H	C	S	D	CS	CD	SD	CSD	X
Males									
H	0.8680	0.0388	0.0430	0.0348	0.0027	0.0021	0.0053	0.0003	0.0051
C	0.0000	0.7919	0.0000	0.0000	0.0542	0.0437	0.0000	0.0063	0.1039
S	0.0000	0.0000	0.7635	0.0000	0.0472	0.0000	0.0935	0.0055	0.0904
D	0.0000	0.0000	0.0000	0.7313	0.0000	0.0449	0.1105	0.0065	0.1068
CS	0.0000	0.0000	0.0000	0.0000	0.3298	0.0000	0.0000	0.0384	0.6318
CD	0.0000	0.0000	0.0000	0.0000	0.0000	0.2840	0.0000	0.0410	0.6750
SD	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.4937	0.0290	0.4773
CSD	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0573	0.9427
X	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000
Females									
H	0.8999	0.0315	0.0331	0.0253	0.0016	0.0015	0.0037	0.0006	0.0027
C	0.0000	0.8300	0.0000	0.0000	0.0432	0.0388	0.0000	0.0157	0.0722
S	0.0000	0.0000	0.7922	0.0000	0.0393	0.0000	0.0884	0.0143	0.0657
D	0.0000	0.0000	0.0000	0.7481	0.0000	0.0437	0.1093	0.0177	0.0812
CS	0.0000	0.0000	0.0000	0.0000	0.3295	0.0000	0.0000	0.1200	0.5505
CD	0.0000	0.0000	0.0000	0.0000	0.0000	0.3064	0.0000	0.1241	0.5695
SD	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.5250	0.0850	0.3900
CSD	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1790	0.8210
X	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000

Table A9: State Transition Probabilities, Age Group 60-64: Basic Scenario (Sc0)

State, age group, 60-64	State, age group 65-69								
	H	C	S	D	CS	CD	SD	CSD	X
Males									
H	0.8029	0.0445	0.0709	0.0522	0.0054	0.0036	0.0091	0.0010	0.0104
C	0.0000	0.6844	0.0000	0.0000	0.0834	0.0556	0.0000	0.0161	0.1606
S	0.0000	0.0000	0.7314	0.0000	0.0559	0.0000	0.0942	0.0108	0.1077
D	0.0000	0.0000	0.0000	0.6831	0.0000	0.0473	0.1195	0.0137	0.1366
CS	0.0000	0.0000	0.0000	0.0000	0.3207	0.0000	0.0000	0.0618	0.6175
CD	0.0000	0.0000	0.0000	0.0000	0.0000	0.2393	0.0000	0.0692	0.6915
SD	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.4429	0.0507	0.5064
CSD	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0910	0.9090
X	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000
Females									
H	0.8893	0.0319	0.0359	0.0313	0.0026	0.0021	0.0033	0.0004	0.0032
C	0.0000	0.7953	0.0000	0.0000	0.0646	0.0512	0.0000	0.0093	0.0796
S	0.0000	0.0000	0.7908	0.0000	0.0571	0.0000	0.0736	0.0082	0.0703
D	0.0000	0.0000	0.0000	0.7771	0.0000	0.0511	0.0831	0.0092	0.0794
CS	0.0000	0.0000	0.0000	0.0000	0.4210	0.0000	0.0000	0.0604	0.5186
CD	0.0000	0.0000	0.0000	0.0000	0.0000	0.3656	0.0000	0.0662	0.5682
SD	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.4840	0.0538	0.4622
CSD	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1043	0.8957
X	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000

Table A10: State Transition Probabilities, Age Group 65-69: Basic Scenario (Sc0)

State, age group, 65-69	State, age group 70-74								
	H	C	S	D	CS	CD	SD	CSD	X
Males									
H	0.7544	0.0796	0.0727	0.0502	0.0109	0.0051	0.0089	0.0016	0.0165
C	0.0000	0.7003	0.0000	0.0000	0.0957	0.0452	0.0000	0.0140	0.1448
S	0.0000	0.0000	0.6576	0.0000	0.0984	0.0000	0.0807	0.0144	0.1489
D	0.0000	0.0000	0.0000	0.6100	0.0000	0.0624	0.1084	0.0193	0.1999
CS	0.0000	0.0000	0.0000	0.0000	0.3760	0.0000	0.0000	0.0550	0.5690
CD	0.0000	0.0000	0.0000	0.0000	0.0000	0.2216	0.0000	0.0687	0.7098
SD	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.3308	0.0590	0.6102
CSD	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0882	0.9118
X	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000
Females									
H	0.8658	0.0393	0.0473	0.0306	0.0033	0.0021	0.0051	0.0005	0.0059
C	0.0000	0.7677	0.0000	0.0000	0.0651	0.0413	0.0000	0.0107	0.1151
S	0.0000	0.0000	0.7606	0.0000	0.0537	0.0000	0.0820	0.0089	0.0949
D	0.0000	0.0000	0.0000	0.6918	0.0000	0.0477	0.1150	0.0124	0.1331
CS	0.0000	0.0000	0.0000	0.0000	0.3410	0.0000	0.0000	0.0562	0.6028
CD	0.0000	0.0000	0.0000	0.0000	0.0000	0.2469	0.0000	0.0642	0.6888
SD	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.4413	0.0476	0.5111
CSD	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0853	0.9147
X	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000

Table A11: State Transition Probabilities, Age Group 70-74: Basic Scenario (Sc0)

State, age group, 70-74	State, age group 75-79								
	H	C	S	D	CS	CD	SD	CSD	X
Males									
H	0.7445	0.0671	0.0857	0.0458	0.0117	0.0076	0.0101	0.0014	0.0262
C	0.0000	0.5888	0.0000	0.0000	0.1027	0.0664	0.0000	0.0119	0.2302
S	0.0000	0.0000	0.6342	0.0000	0.0866	0.0000	0.0749	0.0100	0.1942
D	0.0000	0.0000	0.0000	0.5029	0.0000	0.0831	0.1111	0.0149	0.2880
CS	0.0000	0.0000	0.0000	0.0000	0.2978	0.0000	0.0000	0.0345	0.6677
CD	0.0000	0.0000	0.0000	0.0000	0.0000	0.2153	0.0000	0.0386	0.7461
SD	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.2684	0.0360	0.6957
CSD	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0491	0.9509
X	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000
Females									
H	0.7871	0.0470	0.0901	0.0392	0.0076	0.0026	0.0095	0.0015	0.0155
C	0.0000	0.6337	0.0000	0.0000	0.1023	0.0354	0.0000	0.0196	0.2091
S	0.0000	0.0000	0.7259	0.0000	0.0611	0.0000	0.0763	0.0117	0.1250
D	0.0000	0.0000	0.0000	0.5742	0.0000	0.0385	0.1387	0.0213	0.2273
CS	0.0000	0.0000	0.0000	0.0000	0.3090	0.0000	0.0000	0.0592	0.6318
CD	0.0000	0.0000	0.0000	0.0000	0.0000	0.1342	0.0000	0.0742	0.7916
SD	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.3581	0.0550	0.5869
CSD	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0857	0.9143
X	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000

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