ESTIMATING THE LONG-TERM COSTS OF DIABETIC KIDNEY DISEASE: AN ECONOMIC APPROACH

By

Mark Knezevic^{*}

Business School

University of Western Australia

Abstract

Healthcare spending in Australia has increased rapidly in the past two decades. Part of this has come from the prevalence of lifestyle related illness and demographics, as physical inactivity and ageing have become common. Diabetes is a chronic and costly illness resulting from poor lifestyle choice and ageing. To show the potential future health funding requirements as a result of continuing changes in Australian lifestyle characteristics and demographics, we estimate the long run cumulative costs of a complication of diabetes, diabetic kidney disease, using well known techniques from health economics. We find that spending on treatment for diabetic kidney disease alone will amount to an average of A\$300m per annum for the next thirty years. This figure can be reduced if healthy living habits are promoted in populations at risk.

^{*} The author would like to thank Professor Kenneth W. Clements and Dr. Anh Tram Le of the Business School, University of Western Australia, and Dr. Wendy Davis and Professor Tim Davis of the Fremantle Diabetes Study, Fremantle Hospital, Western Australia. The author would like to acknowledge the UWA Business School for their generous support of this paper.

Introduction

The economics of healthcare has been at the centre of Australian politics since universal healthcare was introduced in the 1970s. Under the Howard government in the late 1990s, government funded universal healthcare came under question. With burgeoning healthcare costs, the government attempted to wean Australians off Medicare, offering incentives to take out private health insurance. The cost of healthcare provision to the Australian Federal Government was at A\$35b in 2004, almost double that of spending on defense at A\$16b and more than education at A\$32b (Costello, 2004 and Commonwealth of Australia Department of Finance, 2004). Healthcare expenditure by Australians amounted to 9.3 per cent of GDP in 2002 (Australian Institute of Health and Welfare, 2003, p. 5). Commonwealth Government spending on health has increased from 1.6 per cent of GDP in 1971 to 4.4 per cent in 2000 (Schofield and Rothman, 2003, p. 4). These trends are set to continue with demographic forecasts showing an ageing Australian population and preference for unhealthy living.

Healthcare is a consistent talking point across Australia. Shortages of hospital beds are often reported in the news media. A call for more doctors in public hospitals and in the bush typifies a system that has a high demand for healthcare. Furthermore, health and lifestyle topics are at the forefront of the public's consciousness. There is constant bombarding of images of obese individuals as an example of a growing obesity epidemic. Several points are borne out of these facts. The Australian population places a high premium on good health and the provision of adequate healthcare services. There is also a sense that already, demand for healthcare outstrips supply. Yet, an ageing population and increasing sedentary lifestyle in the young will only increase demand by placing a greater burden on already strained resources. At some point, the costs of providing healthcare will become very large.

Diabetes is a disease whose primary risk factors are obesity, ageing and poor dietary habits (together with genetics). Diabetes is a prime example of a disease that will lead to future increases in healthcare spending throughout Australia. It is a costly disease because it is chronic and can lead to complications that require medical and hospital treatment. People who develop diabetes may live with the disease for decades. With the rise in inactivity, obesity and ageing there will be an increase

in the proportion of the Australian population who live with the disease. Healthcare expenditure will rise as a result.

Type II diabetes is a condition of elevated blood-sugar levels. The body's organs, the eyes, heart, kidneys, liver and the brain, need a certain level of blood-sugar to work efficiently. A blood-sugar level that is either too high or too low will lead to the failure of one or more of the body's organs. A consistently high blood-sugar level can lead to hypertension, stroke or kidney problems. Each complication requires specific treatment. For instance, hypertension is treated with medication that helps to lower blood pressure, whereas kidney problems may ultimately require dialysis or kidney transplant.

It is easy to understand why the treatment of diabetes before any of these occur is essential, for the consequences are generally fatal, or at the very least, highly debilitating for the patient. Yet the cost of treating diabetic complications is non-trivial for two reasons: 1) diabetes is incurable and the patient will live with the risk of developing any of these complications for decades; and 2) the costs of medical and hospital treatment are high. These direct costs are coupled with indirect costs, that is, the opportunity cost to society of an individual not being able to work because of her case of diabetes.

The Australian Commonwealth Government Institute of Health and Welfare named diabetes one of Australia's top disease priorities (Commonwealth of Australia Department of Health and Ageing, 2004b). The prevalence of the disease (diagnosed and undiagnosed) is currently 6.2 per cent of the population or 850,000 individuals. This is projected to increase to 7.7 per cent of the adult population by 2025 (International Diabetes Federation, 2003b, p. 65). AusDiab already estimates the number of patients with diabetes in Australia to be around 940,000, a prevalence rate of 7.5 per cent (Commonwealth of Australia Department of Health and Ageing, 2004c). In comparison, only 300,000 individuals had type II diabetes in 1981 (National Centre for Monitoring Diabetes, 2002, p. 4 and International Diabetes Federation, 2003b, p. 73). In Australia it is estimated that 2.3 per cent of all deaths can be attributed to diabetes related complications (Diabetes Australia, 2002).

Worldwide, the statistics are similar. The prevalence of diabetes in the US is even higher than in Australia, at 8 per cent of the population, around 20 million cases. The worldwide diabetic population is estimated to be 194 million, 5.1 per cent of the total world population. Out of developed countries, Germany has the highest prevalence rate at 10.2 per cent. India has the highest number of cases at 35.5 million, with China second at around 23.8 million (World Health Organisation, 2002 and International Diabetes Federation, 2003b, pp. 28-67).

Not surprisingly, the direct and indirect costs of diabetes both in Australia and throughout the world are high, and are predicted to grow in coming decades. In 1990 it was estimated that Australia spent A\$420m on diabetes-related treatment (Australian Institute of Health and Welfare, 1994, p. 19). In 2001, DiabCost estimated the cost to be A\$2.1b a year, a figure amounting to 3.6 per cent of national health care expenditure (Davis, 2004, p. 13, quoting DiabCost Australia, 2002). The worldwide cost of diabetes is estimated to be between US\$150-250b (International Diabetes Federation, 2003b).

Given these numbers, various national and international task forces have been set up to analyse the diabetes epidemic and suggest the best methods for reducing the potential development of the disease in populations at risk. There are several well-known lifestyle habits that reduce the risk factors for developing diabetes. These are fairly sensible: living an active lifestyle and eating well. Unfortunately, despite our best wishes, the genetics we are handed at birth cannot be altered, and neither can ageing be reversed.

In this paper, we estimate the long term cost of diabetic kidney disease for the current diagnosed Australian diabetic population based on the data obtained from a longitudinal study of diabetics in the Fremantle area. We extrapolate the data from the Fremantle Diabetes Study (FDS) to the wider Australian population. Second, we determine the effects of adopting an active lifestyle on healthcare spending related to diabetes. Presumably, active patients will be associated with a lower probability of developing kidney failure. We would expect the cost of more active patients to be lower than the cost of less active patients. The results of our model can be used by healthcare administrators and hospitals that treat patients with diabetes, as well as government officials who require aggregate cost information on disease to make budgetary decisions.

We find that the future spending related to diabetic kidney disease is large. As a result, governments should start planning for the coming funding crunch today by promoting preventative measures such as healthy living habits. Contrary to our expectations, we find that inactive patients are marginally less costly than active patients. This perverse conclusion is a result of physically inactive patients having a higher mortality rate than active patients. Nevertheless we still recommend physical activity as an effective strategy for treating diabetes and for preventing the development of diabetic kidney disease.

The layout of the paper is as follows. In the next section, we outline the Markov modelling technique, often used in health economics as a tool for simulating and projecting the development of a disease in a cohort of patients at risk thereby allowing us to estimate the cumulative costs that arise from that disease over a long time frame. The third section presents the results of our model. The final section presents our conclusions and the consequences of the results.

Economic Methodology

There are two approaches to assessing the impact of disease on society. One can be called the epidemiological approach, or the population health approach, which assesses the prevalence and incidence of disease in society. A society with a high prevalence of disease is of course in a worse position than a society with a low prevalence of disease. From an economic perspective, the epidemiological approach gauges the opportunity cost of disease, as disease limits the productiveness of society by incapacitating its population. An alternative approach is a straightforward estimation of the cost of treating disease in patients, that is, the cost of medication and the amount of hospital time spent as a result of illness. This would involve determining what medication is used for a particular disease, and how much hospital care is needed to treat the patient. Of course this neglects the important aspect of the prevalence of the disease in the society. In one sense, the first approach determines how pervasive a disease is in society and whether the risk factors for its development exist in the society or not. The second approach takes the number of patients and risk factors for developing illness as given and merely attempts to estimate how much society has to pay to treat a given number of sick individuals.

In recent decades, methodological developments have allowed a synthesis of these approaches. The field of study within health economics and often used in population health studies is known as cost-effectiveness analysis. Cost-effectiveness analysis compares a number of alternative treatments to an illness in a population at risk. The treatment that minimises costs (in terms of maximum lives saved and minimum expense) is the cost-effective treatment. Cost-effectiveness analysis takes into consideration the probability of the development of an illness and the cost of treating that illness (Garber, 2000, pp. 204-5).

In this study we adopt a well-known health economics tool known as Markov modelling. Markov modelling is used in health economics, cost-effectiveness studies and epidemiological studies to simulate the progression of a disease in a population. With such a simulation we can estimate how much healthcare expenditure will be related to that disease over a long time horizon. It should be noted that we are not running a cost-effectiveness analysis here as we are not solely interested in comparing treatments for diabetes. Instead we are interested in estimating the long term costs of diabetic kidney disease and the difference in costs that occur between a physically active and inactive sample.

A Markov model is defined by four variables: the states of health in which a set of patients reside, the length of time between transitions between states of health, the probability of moving from one state to a new state and the cost of being in each state.

A state of health defines the stage of the disease the simulated set of patients resides in. In the model for diabetic kidney disease there are three stages:

- 1) Preliminary diabetic kidney disease
- 2) Clinical diabetic kidney disease
- 3) End stage kidney disease

Patients' health in the model can progressively worsen, just as in real life. Preliminary diabetic kidney disease is the first and least serious stage of diabetic kidney disease. Once a patient has contracted preliminary diabetic kidney disease she has a certain chance of developing clinical

diabetic kidney disease. Once the patient has clinical diabetic kidney disease, similarly, she can either remain in that health state or progress to end stage kidney disease.¹ Once the patient has contracted preliminary diabetic kidney disease, the model assumes she cannot be cured of it. Therefore the patient either progresses to the clinical stage or remains in the preliminary stage.

Of course, we need to include the case where patients in the sample have diabetes but have not developed any stage of kidney disease. Further, we also want to know the risk of mortality occurring at each state of health. Presumably a sicker patient will have a higher risk of death. Bringing these into our model, the five states of health are:

- 1) Diabetes with no kidney disease
- 2) Preliminary diabetic kidney disease
- 3) Clinical diabetic kidney disease
- 4) End stage kidney disease
- 5) Mortality

Note that individuals without diabetes are excluded. We do this for two reasons: 1) we are interested in kidney-related complications alone; and 2) our data is limited to diabetics only.

When we simulate the model, the aim is to see how the sample population will progress through the various stages of the disease over time. We attempt to replicate what will happen in the wider population: some patients' health will deteriorate; some patients will remain in the same health state; and some patients will die.

When running the simulation, at any point in time there will be certain portions of the sample residing in each state of health. We need to assign the initial state of health for the sample running through the model simulation. We had two alternatives to choose from. We could assume that all patients start the simulation in the no-diabetic kidney disease health state. Or we could assume the distribution of the sample at the start of the model simulation to be equivalent to the distribution of

¹ We assume the patient has preliminary diabetic kidney disease if she has an albumin-creatinine (ACR) ratio of between 3 and 29.9 mg/mmol. A patient has clinical diabetic kidney disease if she has a ratio of over 30 mg/mmol. End stage kidney disease is defined as when a patient requires dialysis.

the sample observed at the beginning of the Fremantle Diabetes Study. We opted for the second approach in order to estimate the future progression of diabetic kidney disease for the present situation of diabetes in Australia. At the first review of the FDS, roughly 32 per cent of the total sample had preliminary diabetic kidney disease and 9 per cent had clinical diabetic kidney disease. The remainder had no kidney problems.

The Markov model simulates the progression of a disease over time. For example, after running the simulation for twenty years, we should expect a certain proportion of the sample to be in each health state. The distribution after twenty years will differ to the initial distribution because after each year, a certain proportion of the sample will progress to subsequent levels of worse health, or indeed, enter the mortality state. In reality, the state of health of an individual cannot be easily categorised into five sets, as we have done here. Further, a patient will have concurrent states of health that affect her well-being and have a bearing on the probability of mortality. Finally, our assumption of homogeneity in the patient sample, that the entire sample has the same probability of worsening illness, is a gross simplification as patients in any sample have different histories and different behaviours that change the risk of illness compared to the mean in the sample. As with any economic model, there are of course shortcomings of our model, and these should be borne in mind when the results are presented.

For the model we need more than just a definition of the states of health individuals can reside in; we require an estimate of the probability of moving from one state of health to another. We estimate these transition probabilities using data from the Fremantle Diabetes Study (FDS). The Fremantle Diabetes Study was a longitudinal study of diabetic patients in the Fremantle area in Western Australia which ran from 1993-2002. Individuals eligible for recruitment had diabetes and lived in the Fremantle area. In total, 1,294 Type II diabetics were recruited to the study. The first review recorded medical, sociological and economic characteristics of the patients. Follow-up reviews recorded the development of diabetes in the sample.

The probability of moving from one disease state to the next is just a conditional probability. The probability of diabetes patients with no kidney disease developing preliminary diabetic kidney disease can be estimated from sample FDS data by taking the ratio of the number of patients without

kidney disease who develop the preliminary stage to the total number of patients in the sample who have no kidney disease and remain that way.

However, due to patients falling out of the survey in the FDS, or censoring, a basic ratio like this would be biased. Instead, we use the technique of incidence density, which is defined as the rate of development of a disease in a population. The incidence density is couched in terms of ‘patient years’ and is calculated as the number of observed new cases of an illness divided by the total number of years patients spend without that illness. For example, examining 16 patients for one year, 8 patients for two years or 32 patients for six months would give us 16 patient years of data. If we observed that 1 patient developed preliminary diabetic kidney disease, the incidence density would give us a ratio of 1/16, or one developed case of preliminary diabetic kidney disease for 16 patient years. The rate of developing the preliminary stage, the incidence density, is in this example, 6.25 per cent (Hennekens and Buring, 1987, p. 57-61).

Incidence density is important to health economics as it can easily augment the number of observations used to calculate the probability of developing a disease. Using incidence density presents a more accurate measure of the probability of developing an illness. For example, there were 249 observed cases of developing preliminary diabetic kidney disease in the FDS out of 2,551 years in which patients had no case of diabetic kidney disease. This is a rate of development of 9.76 per cent. Table 1 presents transitions between states that occurred during the FDS survey and the total patient years for each transition. These numbers are used to calculate incidence densities, the probabilities that appear later in the Markov model.

Table 1
Transitions between States of Health²

a) TRANSITIONS			
	Total Sample	Active	Inactive
S0 to S1	249	183	61
S1 to S2	80	55	24
S2 to S3	11	9	2
S0 to M	36	22	13
S1 to M	36	24	12
S2 to M	63	40	23
S3 to M	10	6	4
b) PATIENT YEARS			
	Total Sample	Active	Inactive
S0 to S1	2,551	2,059	462
S1 to S2	1,988	1,460	525
S2 to S3	1,197	825	349
S0 to M	2,468	2,010	439
S1 to M	1,599	1,161	438
S2 to M	691	478	194
S3 to M	40	23	17

S0: No Kidney Disease
 S1: Preliminary diabetic kidney disease
 S2: Clinical Kidney Disease
 S3: End stage kidney disease
 M: Non-Specific Mortality State

The probability that an individual with clinical diabetic kidney disease will develop end stage kidney disease is the incidence density for that set of patients in the FDS. The probability of mortality is estimated for each state of health. However, we assume that patients cannot skip a state of health for simplicity and because very few patients were found to have done this in the sample data. We make a further assumption that the probability of mortality will increase as an individual ages at the same rate that this probability increases in the wider population. Data limitations on mortality in the FDS required us to make this assumption. We use ABS Life Tables to estimate the

² The active and inactive sub-sample observations will not sum to the total sample in some instances because of missing observations on activity status in the FDS.

rate at which the probability of mortality increases with age (around 10 per cent for the age bracket we are examining).

The transition probability matrix for the total sample is presented in Table 2. The transition probabilities presented in the matrix are based on the numbers presented in Table 1. The confidence intervals associated with these estimates are presented in Table 3. The interpretation of the matrix is as follows. The cell in the first row, second column (S0-S1) is the probability that a patient will progress from having no kidney disease to having first stage kidney disease within a year. The chance that an individual with no diabetic kidney disease will die within a year is given by the first row, fifth column (S0-M).

As expected, patients will on average not develop significantly worse health within a year. The probabilities in the main diagonal are by far the largest in the matrix. Similarly, the probability of mortality increases as an individual's health worsens, shown by the numbers in the M column increasing as we move down the column. Finally, the matrix rows necessarily sum to one; if they did not sum to one, a portion of the patient cohort would fall out of the model. This explains why the chance of remaining in the mortality state (row four, column four) is 1 in the matrix. Once an individual has passed away, it is assumed with a fair amount of certainty that she cannot come back to life. The mortality state is called an 'absorbing state', as eventually, if the Markov simulation is run long enough, the entire sample will end up in it (to paraphrase Keynes).

Table 2
Markov Transition Probability Matrix

	S0	S1	S2	S3	M
S0	0.8878	0.0976	0	0	0.0146
S1	0	0.9372	0.0402	0	0.0225
S2	0	0	0.8996	0.0092	0.0912
S3	0	0	0	0.7500	0.2500
M	0	0	0	0	1

S0: No Kidney Disease
S1: Preliminary diabetic kidney disease
S2: Clinical Kidney Disease
S3: End stage kidney disease
M: Non-Specific Mortality State

Table 3
95 per cent Confidence Intervals

	S0	S1	S2	S3	M
S0	(0.87-0.90)	(0.09-0.11)	0	0	(0.01-0.02)
S1	0	(0.92-0.95)	(0.03-0.05)	0	(0.02-0.03)
S2	0	0	(0.87-0.93)	(0.01-0.015)	(0.07-0.11)
S3	0	0	0	(0.61-0.88)	(0.12-0.38)
M	0	0	0	0	1

S0: No Kidney Disease
 S1: Preliminary diabetic kidney disease
 S2: Clinical Kidney Disease
 S3: End stage kidney disease
 M: Non-Specific Mortality State

For simplicity it is assumed that patients have the potential to move from one state of health to a new state of health on an annual basis only. Therefore, the model does not account for cases in which a patient develops preliminary diabetic kidney disease and then develops clinical diabetic kidney disease within six months of the first development. This assumption is also due to data limitations, as the Fremantle Diabetes Study is based on an annual review of its patients.

The cost of being in a state of health is simply the cost of treating that state. For example, preliminary diabetic kidney disease requires medical treatment. Clinical diabetic kidney disease requires more vigorous treatment than the preliminary stage and end stage kidney disease requires dialysis. Because we assume that a patient is in a disease state for at least a year, costs are annualised. The treatment for each state of health is presented in Table 4. The costs of treating each state, based on the given treatments, are presented in Table 5. These are based on published information in the Australian Medical and Pharmaceutical Benefits Scheme in consultation with WA kidney specialist, Dr Mark Thomas. It is assumed that there is no treatment given to a diabetic in order to calculate the spending specifically related to diabetic kidney disease alone. As expected, the costs of treatment increase with a worsening degree of kidney disease. On an annualised basis, the cost of treating the clinical stage is almost twenty times as great as the cost of treating the preliminary stage. The cost of treating the end stage is six times as great as the cost of treating the clinical stage.

Table 4
Treatment for Diabetic Kidney Disease

State of Health	Treatment
Preliminary Kidney Disease	ACE-Inhibitors
Clinical Kidney Disease	ACE-Inhibitors
	Erythropoietin
	Four outpatient visits
End Stage Kidney Disease	Dialysis

Source: MBS; PBS; Dr. Mark Thomas

Table 5
Costs of Treating Diabetic Kidney Disease in Australia

State of Health	Weekly Cost (A\$)	Annual Cost (A\$)
Preliminary Kidney Disease	10.5	540
Clinical Kidney Disease	203	10,535
End Stage Kidney Disease	1,195	62,132

Source: MBS; PBS

Taken together, the above variables, set in a Markov framework, will provide an estimate of the development of diabetic kidney disease in a population with diabetes, from which its cumulative costs can be estimated. The model will run until at least 95 per cent of the sample cohort enters the mortality state, or for thirty years, whichever comes first. Finally, future costs need to be discounted into present value figures. A discount rate of 3 per cent is assumed based on the upper bound inflation target of the Reserve Bank of Australia. This simple calculation converts future dollars into present dollars.

The Fremantle Diabetes Study recorded such characteristics as whether or not patients were physically active or inactive at the first review. Many studies have shown that exercise reduces the risk of developing diabetic kidney disease, and indeed, diabetes in general (Palmer et al. 2004, p. 304; Fredrickson, Ferro and Schutrumpf, 2004, pp. 1754-1755; Wolf et al. 2004, p. 1570 and Klein

et al. 2004, pp. 2067-70). In addition to an overall estimate of the costs of diabetic kidney disease arising from the current Australian diabetic population, we would like to assess the long term implications of a physically active set of diabetes patients against a physically inactive set of diabetes patients, and to determine whether, as we hypothesise, a patient sample that is physically active has a smaller burden on the healthcare community than a patient sample that is physically inactive.

To do this we stratify two cohorts in the FDS, based on whether they were physically active or not. Transition probabilities (and their confidence intervals) are estimated for each sub-sample. The results are shown in Tables 6 and 7. These tables should be interpreted much like the matrix presented in Table 2. Predictably, the active cohort has lower transition probabilities to mortality and to subsequent stages of diabetic kidney disease, apart from patients with end stage kidney disease, in which the active sample has a higher probability of mortality.³ Using these transition probabilities and assigning the same costs to health states in the model will provide a comparison of long run costs in the two cohorts, thereby determining effect of physical activity on healthcare spending over time.

Table 6
Markov Transition Probability Matrix: Active Sample

	S0	S1	S2	S3	M
S0	0.9002	0.0889	0	0	0.0109
S1	0	0.9417	0.0377	0	0.0207
S2	0	0	0.9054	0.0109	0.0837
S3	0	0	0	0.7391	0.2609
M	0	0	0	0	1

S0: No Kidney Disease
S1: Preliminary diabetic kidney disease
S2: Clinical Kidney Disease
S3: End stage kidney disease
M: Non-Specific Mortality State

³ Under our assumption, clinical stage kidney disease is treated with dialysis. This requires the patient to spend a lot of time in hospital care and greatly reduces the potential for physical activity. As a result it is possible that the health benefits of activity breakdown at this stage of the disease. The probability of mortality between the two sub-samples may converge as our results show.

Table 7
Markov Transition Probability Matrix: Inactive Sample

	S0	S1	S2	S3	M
S0	0.8384	0.1320	0	0	0.0296
S1	0	0.9269	0.0457	0	0.0274
S2	0	0	0.8757	0.0057	0.1186
S3	0	0	0	0.7647	0.2353
M	0	0	0	0	1

S0: No Kidney Disease
 S1: Preliminary diabetic kidney disease
 S2: Clinical Kidney Disease
 S3: End stage kidney disease
 M: Non-Specific Mortality State

Results

The total cost and cost of each state of health on a per patient basis is presented in Table 8. The second column in the table, *Total Cost*, suggests that on average, a patient who has diabetes now is projected to cost the healthcare system A\$17,185. Around \$2,900 of this will come from treating preliminary diabetic kidney disease, \$13,000 will come from treating the clinical stage, and \$1,200 will come from treating the end stage of the complication.

Table 8
Projected Per Patient Cost of Diabetic Kidney Disease
(A\$ 2001)

	Total Cost (95% CI)	Preliminary	Clinical	End Stage
Total Sample	17,185 (15,932 - 18,649)	2,907	13,042	1,237
Active	17,273 (15,695 - 19,282)	2,979	12,905	1,390
Inactive	16,054 (14,280 - 18,373)	2,802	12,451	801

We extrapolate the results of the total FDS sample for the estimated current size of the diagnosed diabetic population in Australia (520,000 individuals based Australian Diabetes estimates).⁴ The results are presented in Table 9. We project that Australia will spend A\$9.2b on medical and hospital treatment for diabetic kidney disease over the next thirty years. A\$1.5b will be spent on treating the preliminary stage; A\$6.7b will be spent on treating the clinical stage and A\$643m will be spent on treating the end stage of the complication.

Table 9
Projected Australian Costs of Diabetic Kidney Disease
(A\$m 2001)

	Total Cost	S1 Cost	S2 Cost	S3 Cost
Total Sample	9,264	1,512	6,782	643

Tables 8 and 9 show that most of the cost comes from treating the clinical stage of the disease. Given that this stage of the disease requires greater treatment than the preliminary stage, this comes as no surprise. However, the clinical stage costs more than the end stage, despite the fact that when looking at the treatments required for each stage, the end stage (requiring dialysis) is far more expensive than the clinical stage. This is explained by the fact that few patients in our model were observed to develop end stage kidney disease. This is of some consequence to government policy makers. A great deal of media attention was given to the cost of treating end stage kidney disease in late 2004, but our results show this attention should have been directed at the clinical stage.⁵

Surprisingly, there was very little difference in total costs between the physically active and inactive sub-samples. This is borne out by both the point and confidence interval estimates. The difference that was found (although small) suggests that the active sample was more costly than the inactive sample. To explain this, we present Figure 1, which shows the accumulation of total costs over time, on a per patient basis, and the survival curve simulated by the Markov model.

⁴ We used the diagnosed population as this is the number of patients who will receive medical treatment. We assume the undiagnosed population will not receive medical treatment for their diabetes.

⁵ For example, see <http://seven.com.au/news/nationalnews/113009> [Accessed: 27/9/2004].

Figure 1
Accumulation of Costs (per patient)

Figure 2
Survival Curves

A survival curve shows the proportion of patients that remain in the Markov model after a number of years. Because the only way to exit the model is by entering the mortality state, the decay in survival is necessarily a result of individuals dying. Figure 2 shows that patients in the inactive sample exited the system at a faster rate than patients in the active sample, and indeed, than patients in the entire sample. The implication of this is that the inactive sample, which was found to be slightly less healthy than the active cohort based on the rates of transition from healthy states to less healthy states exits the healthcare system at a greater rate because of higher mortality, and therefore over a long term horizon, uses up fewer hospital resources than the active sample. This explains the result in Table 8 above and Figure 1, which show the overall costs in the active sample are greater than the inactive sample.

Discussion and Implications

We have shown that the future costs of diabetic kidney disease arising from the current diagnosed diabetic population will be large, warranting continued research to find methods for limiting the contraction of diabetes in the wider population. Based on our results, dealing with diabetes should remain one of the government's health priority areas.

Although we found that the healthcare costs of active diabetics was in fact larger than inactive diabetics, this result was small and we see no reason not to recommend physical activity as an effective means for treating diabetes and diabetic kidney disease. The higher cost from the active sample is a result of increased mortality rate in the inactive sample. Physically active diabetics live longer, and although this increases the healthcare spending, there is surely a large benefit to society from individuals living longer. Our study did not set out to assess the potential health benefits of physical activity, only the implications for direct economic costs.

The model projects that the most significant cost will come from the clinical stage of diabetic kidney disease. This cost will start to hit society a decade or so after the initial onset of diabetes, as individuals with diabetes start to progress to clinical diabetic kidney disease. The point is that action has to be taken now to limit the potential progression to diabetes and the debilitating complications that follow, to limit future healthcare spending. This can come in many forms: educating the public as to the potential costs to society; educate the public-at-risk as to the potential individual impact

diabetes can have; and of course, educating the public as to the best methods of staving off the contraction of diabetes, namely, encouraging an active lifestyle and good dietary habits. Healthcare costs will only rise in the future as more individuals at risk begin to succumb to illness such as diabetes, and its subsequent complications such as diabetic kidney disease.

Our model of diabetic kidney disease serves as an example as to what will start to happen to the Australian healthcare system as a whole. Just as in our model, when diabetics developed complications over time, as the wider population ages and becomes less healthy more individuals will require healthcare. As more individuals require healthcare, the amount spent to provide it will increase, taking away money that may be spent elsewhere. Based on our findings that the cost of diabetic kidney disease, alone, will be large, and that costs will rise into the future, the government cannot continue to simply treat illnesses such as diabetes with increased health expenditure in hospitals and continued subsidisation of medication and treatment. At some point the prevalence of such diseases will become too great for the system to handle. Instead, methods must be adopted now to reduce the potential development of the disease in populations at risk. Public officials should be aware of the potential future dangers now in order to take the required action.

References

- Adler, A. I., R. J. Stevens, S. E. Manly, R. W. Bilous, C. A. Cull and R. R. Holman (2003). "Development and Progression of Nephropathy in Type 2 Diabetes: The United Kingdom Prospective Diabetes Study (UKPDS 64)." Kidney International 63: 225-232.
- American Diabetes Association (2004a). Diabetes Fact Sheet. Available at <<http://www.diabetes.org/diabetes-statistics/national-diabetes-fact-sheet.jsp>> [Accessed: 31/7/2004].
- _____ (2004b). "Diabetes Care Supplement." Diabetes Care 27: S1-150.
- Anderson, J. S. and K. W. Clements (1982). "Holdings of Financial Assets: A Markov Chain Analysis." Statistics and Probability Letters 1: 36-40.
- Anonymous (1998). "Economic Study Highlights Enormous Burden of Diabetes." Diabetes Forecast 51: 57.
- Australian Bureau of Statistics (2002). Deaths, Cat. No. 3302.0. ABS, Canberra.
- Australian Institute of Health and Welfare (2003). Health Expenditure Australia 2001-2002 AIHW Cat. No. HWE-24. Available at <<http://www.aihw.gov.au/publications/hwe/hea01-02/hea01-02.pdf>> [Accessed: 31/7/2004].
- _____ (1994). Health System Costs of Cardiovascular Diseases and Diabetes in Australia 1993-1994 AIHW Cat. No. HWE-11. Available at <<http://www.aihw.gov.au/publications/health/hscdda93-4/hscdda93-4.pdf>> [Accessed: 26/1/2006].
- Barcelo, A., C. Aedo, S. Rajpathak, and S. Robles, "The Cost of Diabetes in Latin American and the Caribbean." The Bulletin of the World Health Organization 81: 19-27. Available at <http://www.scielo.org/scielo.php?pid=S004296862003000100006&script=sci_arttext&dtlng=en> [Accessed: 7/9/2004].
- Bjørk, S. (2001). "The Cost of Diabetes and Diabetes Care." Diabetes Research and Clinical Practice 54: S13-18.
- Brown, J. B., A. Russell, W. Chan, K. Pedula and M. Aickin (2000). "The global diabetes model: user friendly version 3.0." Diabetes Research and Clinical Practice 50: S15-S46.
- Borgan, Ø. (2002). "Estimation of covariate-dependent Markov transition probabilities from nested case-control data." Statistical Methods in Medical Research 11: 183-202.
- Caro, J. J., A. J. Ward and J. A. O'Brien (2002). "Lifetime Costs of Complications Resulting from Type 2 Diabetes in the US." Diabetes Care 25: 476-481.

- Cameron, A. J., P. Z. Zimmet, D. W. Dunstan, N. Owen, J. Salmon, M. Dalton, D. Jolley and J. E. Shaw (2003). "Overweight and Obesity in Australia: the 1999-2000 Australian Diabetes, Obesity and Lifestyle Study (AusDiab). Medical Journal of Australia 178: 427-432.
- Chawla, H. P. S., N. Diwan and K. Joshi (2004). Emerging Trends in the World Pharmaceutical Market – A Review. Touch Briefing Series, available at <http://www.bbriefings.com/pdf/790/8-chawla.pdf> [Accessed: 31/7/2004].
- Commonwealth of Australia Department of Finance (2004). 2004-2005 Budget Overview. Available at http://www.finance.gov.au/Budget/2004-05/overview/download/budget_overview.pdf [Accessed: 31/7/2004].
- Commonwealth of Australia Department of Health and Ageing (2004a). National Diabetes Services Scheme. Available at <http://www.health.gov.au/pbs/pharm/supply/ndss.htm> [Accessed: 31/7/2004].
-
- (2004b). Expenditures and Prescriptions of the Pharmaceutical Benefits Scheme. Available at <http://www.health.gov.au/pbs/general/pubs/pbbexp/pbmar04/pdf/bookp01.pdf> [Accessed: 31/7/2004].
-
- (2004c). Diabetes: Data and Trends. Available at <http://www.health.gov.au/pq/diabetes/data.htm> [Accessed: 10/9/2004].
-
- (1998). National Health Priority Areas Report: Diabetes Mellitus AIHW Cat. No. PHE 10. Available at <http://www.health.gov.au/pq/diabetes/pdf/diab98.pdf> [Accessed: 31/7/2004].
- Commonwealth Department of Health and Aged Care (1999). Medicare Schedule Benefits Book. Canberra.
- Commonwealth Department of Human Services and Health (2000). Schedule of Pharmaceutical Benefits. Canberra.
- Costello, P. (2004). Australian Commonwealth Budget Speech, 2004-2005. Available at <http://www.budget.gov.au/2004-05/speech/html/speech.htm> [Accessed: 31/7/2004].
- Davey, P., S. Colagiuri, B. Conway, D. Grainger, R. Colagiuri, P. Graham-Clarke, P. FitzGerald, C. Le Reun and N. Price (2003). Cost of Type 2 Diabetes Care in Australia - the DiabCost Study. Medical Technology Assessment Group, available at http://www.m-tag.net/ISPORJAP2003_DIABCOST_PCSD1.pdf [Accessed: 31/7/2004].
- Davis, W. (2004). The Direct Health Care Costs of Type 2 Diabetes Mellitus in a Community Setting: The Fremantle Diabetes Study. PhD Thesis, University of Western Australia.

- DiabCost Australia (2002). Assessing the burden of type 2 diabetes in Australia. Adelaide, Australian Diabetes Society, Australian Diabetes Educators Association Annual Scientific Meeting.
- Diabetes Australia (2002). Diabetes Facts. Available at http://www.diabetesaustralia.com.au/lib/doc_pdf/Diabetesfactsheet.pdf [Accessed: 31/7/2004].
- Diabetes UK (2004). Fact Sheet Number 3: Costs and Complications. Available at <http://www.diabetes.org.uk/infocentre/fact/fact3.htm> [Accessed: 26/8/2004].
- Dunstan, D. W., P. Z. Zimmet, T. A. Welborn, A. J. Cameron, J. Shaw, M. de Courten, D. Jolley, D. J. McCarty and AusDiab Steering Committee (2002). "The Australia Diabetes, Obesity and Lifestyle Study (AusDiab) - methods and response rates." Diabetes Research and Clinical Practice 57: 119-129.
- Eddy, D. M. and L. Schlessinger (2003a). "Archimedes: A Trial-validated model of diabetes." Diabetes Care 26: 3093-3101.
- _____ (2003b). "Validation of the Archimedes Diabetes Model." Diabetes Care 26: 3102-3110.
- Fredrickson, S. K., T. J. Ferro, and A. C. Schutrumpf (2004). "Disappearance of Preliminary diabetic kidney disease in a Patient with Type 2 Diabetes and the Metabolic Syndrome in the Setting of an Intense Exercise and Dietary Program with Sustained Weight Reduction." Diabetes Care 27: 1754-1755.
- Garber, A. M. (2000). "Advances in CE Analysis," in Handbook of Health Economics 1A, eds. Culyer, A. J. and Newhouse, J. P., Elsevier Science, Amsterdam, pp. 181-221.
- Gordois, A., P. Scuffham, A. Shearer and A. Oglesby (2004). "The Health Care Costs of Diabetic Nephropathy in the United States and the United Kingdom." Journal of Diabetes and Its Complications 18: 18-26.
- Hazen, G. B., J. M. Pellissier and J. Sounderpandian (1997). Stochastic Tree Models in Medical Decision Making. Northwestern University, Evanston/Chicago, available at http://users.iems.northwestern.edu/~hazen/Interfaces_Final_Version.PDF, [Accessed: 31/7/2004].
- Herman, W. H. (2003). "Diabetes Modeling." Diabetes Care 26: 3182.
- Hennekens, C. H. and J. E. Buring (1987). Epidemiology in Medicine. Little Brown and Co., Boston.
- Hogan, P., T. Dall and P. Nikolov (2003). "Economic Costs of Diabetes in the US in 2002." Diabetes Care 26: 917-932.

- Hui-Min, W., Y. Ming-Fang and T. H. Chen (2004). "SAS macro program for non-homogeneous Markov process in modeling multi-state disease progression." Computer Methods and Programs in Biomedicine 75: 95-105.
- International Diabetes Federation (2003a). Cost Effective Approaches to Diabetes and Diabetes Care. International Diabetes Federation, Brussels.
- _____ (2003b). Diabetes Atlas. International Diabetes Federation, Brussels.
- Isaacson, D. L. and R. W. Madsen (1976). Markov Chains: Theory and Applications. John Wiley and Sons, New York.
- Ismail, N., B. Becker, P. Strzelczyk and E. Ritz (1999). "Renal disease and hypertension in non-insulin-dependent diabetes mellitus." Kidney International 55: 1-28.
- Klein, S., N. F. Sheard, X. Pi-Sunyer, A. Daly, J. Wylie-Rosett, K. Kulkarni and N. G. Clark (2004). "Weight Management Through Lifestyle Modification for the Prevention and Management of Type 2 Diabetes: Rationale and Strategies (Statement of the American Diabetes Association, the North American Association for the Study of Obesity, and the American Society for Clinical Nutrition)." Diabetes Care 27: 2067-73.
- Klein, J. P and C. Qian (1996). Modelling multistate survival illustrated in bone marrow transplantation. Division of Biostatistics, University of Wisconsin. Available at <http://www.biostat.mcw.edu/tech/tr015.pdf> [Accessed: 9/9/2004]
- Kuntz, K. M. and M. C. Weinstein (2001). "Modelling in Economic Evaluation," in Economic Evaluation in Health Care eds. Drummond, M. and McGuire, A., Oxford University Press, Oxford, pp. 141-171.
- Lasker, R. (1993). "The Diabetes Control and Complications Trial – Implications for Policy and Practice." The New England Journal of Medicine 329: 1035-6.
- McCullough, P. A., G. L. Bakris, W. F. Owen Jr., P. S. Klassen and R. M. Califf (2004). "Slowing the Progression of Diabetic Nephropathy and its Cardiovascular Consequences." American Heart Journal 148: 243-51.
- Muening, P. and K. Kahn (ed.) (2002). Cost-Effectiveness Analysis in Medicine and Health Care. John Wiley and Sons, San Francisco.
- Murakami, Y. and Y. Ohashi (2001). "Projected number of diabetic renal disease patients among insulin-dependent diabetes mellitus children in Japan using a Markov model with probabilistic sensitivity analysis." International Journal of Epidemiology 30: 1078-1083.

- Naimark, D., M. D. Krahn, G. Naglie, D. A. Redelmeier and A. S. Detsky (1997). "Primer on Medical Decision Analysis: Part 5 – Working with Markov Processes." Medical Decision Making 17: 152-59.
- National Association of Diabetes Centres (2003). Australian National Diabetes Information Audit and Benchmarking (ANDIAB) - Final Report. Commonwealth of Australia Department of Health and Ageing, Canberra, available at <<http://www.health.gov.au/pq/diabetes/pdf/andiabreptjan03.pdf>> [Accessed: 16/9/2004].
- National Centre for Monitoring Diabetes (2002). Diabetes: Australian Facts AIHW Cat. No. CVD 20. Commonwealth of Australia Department of Health and Ageing, Canberra, available at <<http://www.aihw.gov.au/publications/cvd/daf02/daf02.pdf>> [Accessed: 9/9/2004].
- Niessen, L. W. (2002). Roads to Health: Multi-state modelling of population health and resource use. Groningen University Library, Groningen, available at <<http://www.ub.rug.nl/eldoc/dis/rw/l.w.niessen/>> [Accessed: 9/9/2004].
- Organisation for Economic Co-operation and Development (2004). Health Data, June 2004. Available at <<http://www.oecd.org/dataoecd/3/62/31938359.pdf>> [Accessed: 31/7/2004].
- Os, N. van, L. W. Niessen, H. J. G. Bilo, A. F. Casparie and B. A. van Hout (2000). "Diabetes nephropathy in the Netherlands: a cost effectiveness analysis of national clinical guidelines." Health Policy 51: 135-147.
- Paes, A. T. and A. C. P. de Lima (2004). "A SAS macro for estimating transition probabilities in semiparametric models for recurrent events." Computer Methods and Programs in Biomedicine 75: 59-65.
- Palmer, A. J., C. Weiss, P. P. Sendi, K. Neeser, A. Brandt, G. Singh, H. Wenzel and G. A. Spinas, (2000). "The cost-effectiveness of different management strategies for Type I diabetes: a Swiss perspective." Diabetologia 43: 13-26.
- Palmer, A. J., S. Roze, W. J. Valentine, G. A. Spinas, J. E. Shaw and P. Z. Zimmet (2004). "Intensive lifestyle changes or metformin in patients with impaired glucose tolerance: modeling the long-term health economic implications of the diabetes prevention program in Australia, France, Germany, Switzerland, and the United Kingdom." Clinical Therapeutics 29: 304-21.
- Patterson, K. (2003). Health Budget for 2003-2004. Commonwealth of Australia Department of Health and Ageing, available at <<http://www.health.gov.au/budget2003/book.htm>> [Accessed: 31/7/2004].

- Reserve Bank of Australia (2004). Bulletin Statistical Tables: Prices and Output. Available at http://www.rba.gov.au/Statistics/Bulletin/index.html#table_g [Accessed: 20/8/2004].
- Richard, A., S. Richardson and J. Maccario (1993). "A Three-State Markov Model of *Plasmodium falciparum* Parasitemia." Mathematical Biosciences 117: 283-300.
- Ritz, E., (1999). "Nephropathy in type 2 diabetes." Journal of Internal Medicine 245: 111-126.
- Roper, N. A., R. W. Bilous, W. F. Kelly, N. C. Unwin and V. M. Conolly (2002). "Cause-Specific mortality in a population with diabetes: South Tees Mortality Study." Diabetes Care 25: 43-48.
- Schofield, D. and G. Rothman (2003). "Projections of Commonwealth Health Expenditure," presented at the International Microsimulation Conference on Population, Ageing and Health: Modelling Our Future. Canberra, National Centre for Social and Economic Modelling, available at http://www.natsem.canberra.edu.au/conference/papers/pdf/schofield_deborah-1.pdf
- Selby, J. V., D. Zhang, G. T. Ray and C. J. Colby (1997). "Excess Costs of Medical Care for Patients With Diabetes in a Managed Care Population." Diabetes Care 20: 1396-1402.
- Singh, K. P., S. Bae, A. A. Bartolucci, R. I. Chowdhury, M. A. Islam and Warsono (1999). "Estimation of Transition Rates in a Multi-State Proportional Hazards Model." Environment International 25: 781-5.
- Stephenson, J., A. Bauman, T. Armstrong, B. Smith, and B. Bellew (2000). The Costs of Illness Attributable to Physical Inactivity in Australia. Commonwealth of Australia Department of Health and Aged Care. Available at http://www.health.gov.au/pubhlth/publicat/document/phys_costofillness.pdf [Accessed: 26/8/2004].
- Theil, H. (1972). Statistical decomposition analysis with applications in the social and administrative sciences. North-Holland, Amsterdam.
- TreeAge Software Inc. (2004). TreeAge Pro Suite, Student Edition. TreeAge Software Inc., Williamstown.
- US Federal Department of Health and Human Services Center for Disease Control and Prevention (2002). Federal Agencies team up with business to ease burden of diabetes as work (Press release: 11/11/2002). Available at <http://www.cdc.gov/od/oc/media/pressrel/r021111.htm> [Accessed: 31/7/2004].
- Wales4Innovation (2001). Computer Predictions for diabetes (a synopsis). Advances Wales Magazine, available at http://www.wales4innovation.co.uk/pooled/articles/BF_WEBART/view.asp?Q=BF_WEBART_23478 [Accessed: 16/9/2004].

- Waters, E. B. and L. A. Baur (2003). "Childhood obesity: modernity's scourge." Medical Journal of Australia 178: 422-423.
- Wild, S., G. Roglic, A. Green, R. Sicree and H. King (2004). "Global Prevalence of Diabetes: Estimates for the year 2000 and projections for 2030." Diabetes Care 27: 1047-1053.
- Wolf, A. M., M. R. Conaway, J. Q. Crowther, K. Y. Hazen, J. I. Nadler, B. Oneida and V. E. Bovbjerg (2004). "Translating Lifestyle Intervention to Practice in Obese Patients With Type 2 Diabetes." Diabetes Care 27: 1570-1576.
- World Health Organisation (2002). Diabetes: The Cost of Diabetes, Fact Sheet No. 236. Available at <<http://www.who.int/mediacentre/factsheets/fs236/en/>> [Accessed: 31/7/2004].
- Yu, F., H. Morgenstern, E. Hurwitz and T. R. Berlin (2003). "Use of a Markov transition model to analyse longitudinal low-back pain data." Statistical Methods in Medical Research 12: 321-31.
- Yuyun, M. F., S. F. Dinneen, O. M. Edwards, E. Wood and N. J. Wareham (2003). "Absolute Level and Rate of Change of albuminuria over 1 year independently predict mortality and cardiovascular events in patients with diabetic nephropathy." Diabetic Medicine 20: 277-82.