MODELLING PATIENT DECISION-MAKING AMONG MANITOBANS IN THE CONTEXT OF TYPE II DIABETES MELLITUS (T2DM)

BY

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DECLARATION REGARDING APPLICATION OF STATISTICS CANADA PUBLIC USE MICRODATA FILES

The analysis undertaken in Section 3.5.1 in Chapter 3 is based on Statistics Canada's National Household Survey Public Use Microdata, which contains anonymized data collected in the National Household Survey.

The analysis undertaken in Section 3.6.4 in Chapter 3 is based on Statistics Canada's Survey of Labour and Income Dynamics Public Use Microdata, which contains anonymized data collected in the Survey of Labour and Income Dynamics.

All computations on these microdata were prepared by Matthew Stargardter. The responsibility for the use and interpretation of these data is entirely that of the author.

DECLARATION REGARDING APPLICATION OF THE DIABETES POPULATION RISK TOOL AND THE UNITED KINGDOM PROSPECTIVE DIABETES STUDY OUTCOMES MODEL

The analysis undertaken in Section 3.6.1 in Chapter 3 draws upon the Diabetes Population Risk Tool, Version 2.0 (DPoRT 2.0) risk equations published in Rosella, Lebenbaum, Li, Wang, and Manuel (2014). This analysis and all computations utilizing the equations were prepared by Matthew Stargardter.

While results are not presented explicitly in the body of this thesis, model parameters relating to the probability of all-cause mortality in T2DM patients (discussed in Section 3.6.2 in Chapter 3), and workplace absenteeism and health-related quality of life decrements attributable to T2DM (discussed in Section 3.5.3 in Chapter 3), are based on simulations undertaken using the United Kingdom Prospective Diabetes Study Outcomes Model, Version 2.0 (UKPDS-OM2), which is licensed to academic organizations by the University of Oxford.

The selection of parameter values for the UKPDS-OM2 and all computations drawing upon simulation results were prepared by Matthew Stargardter. Responsibility for interpretation of results generated using the DPoRT 2.0 risk equations or the UKPDS-OM2, and for application of said results or of these resources more generally, is entirely that of the author.

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ABSTRACT

This thesis documents the development and implementation of a dynamic, stochastic model of decision-making in the context of type 2 diabetes mellitus (T2DM), with specific reference to the Province of Manitoba.

The second chapter (i.e., after the introduction) informs development of the model by summarizing the state of knowledge regarding T2DM and surveying existing economic models and frameworks. T2DM is a chronic condition that can reduce life expectancy, adversely affect labour market performance, and profoundly impact quality of life. People can reduce their risk of T2DM and manage its progression in various ways but exert limited control over health outcomes. Within this context, this thesis studies optimal decision-making by fully-rational, forward-looking individuals by extending Peter Zweifel, Friedrich Breyer, and Mathias Kifmann's model of health production and demand.

The third chapter conceptualizes health-related decision-making as a dynamic optimization problem in which health and economic events constitute transitions between predefined states. T2DM and its complications detract from quality of life, increase mortality risk, and restrict opportunities to engage in consumption and leisure. People can reduce, but not eliminate, the chance of developing T2DM and the rate of diabetic progression through regular physical activity and

adherence to healthy eating habits and pharmacotherapy, but only by sacrificing time and income that could be allocated to other things. The model cannot be solved analytically but is amenable to application of numerical techniques. The remainder of Chapter 3 selects values or ranges for model parameters to reflect the circumstances in which Manitobans make health-related decisions.

The fourth chapter describes model implementation, interprets key results, and illustrates potential applications. Fully-rational, forward-looking individuals are generally motivated to invest in health, but this is mediated by their circumstances and personal characteristics, and they may sometimes trade off increased risk of adverse health outcomes or accelerated rate of diabetic progression in return for more consumption or leisure. Microsimulations based on these results suggest opportunities to reduce efficiency losses attributable to T2DM in Manitoba through improved health-related decision-making, but this requires investing in both T2DM prevention and management, and may entail altering the structure of incentives within which choices are made.

ACKNOWLEDGEMENTS

I would be profoundly remiss if I did not take this opportunity to recognize the multitude of contributions others made to this study, without which it would surely have failed. My greatest debt is unquestionably to my Thesis Advisor, Dr. Gregory Mason, who freely offered up his boundless knowledge and experience at every stage, and never ceased to advocate on my behalf. I would also like to express my deepest gratitude to Dr. Julia Witt, Dr. Alan Katz, and Dr. Wayne Simpson for serving on my Advisory Committee, and for graciously contributing their time and expertise to ensure the success of this research.

As I prepared this thesis I was consistently and pleasantly surprised at the willingness of colleagues, acquaintances, and oftentimes complete strangers to support my work in one way or another. I thank Mark Nagelberg and Marcus Morrisey for their invaluable assistance as I sought to master the programming skills necessary to achieve my research objectives, and the Partners at PRA, Inc. for permitting me to adopt flexible work arrangements over the last several years. I also wish to recognize Dr. Laura Rosella and Kathy Kornas, who helped me apply the DPoRT 2.0 risk equations; Dr. Paul Komenda, who helped me refine my research methodology; Michelle Glass, who helped inform the pharmaceutical costing exercise; and Dr. Doug Coyle and several individuals at the University of Oxford who helped me fully exploit the functionality of the UKPDS-OM2.

An early phase in this research involved carrying out expert elicitation exercises with Manitoba family physicians. While the results of these exercises were ultimately not incorporated into this thesis, I am nonetheless deeply grateful for the contributions of Zia Hameed at PRA, Inc., Dr. Shaun Gauthier and Becky Szucki at Prairie Mountain Health, Darcy Bell at Brandon Clinic Medical Corporation, Sandi Levandoski at Western Medical Clinic, and Betty McGregor in the Department of Economics at the University of Manitoba, who facilitated the implementation of the physician survey; Dr. Saumen Mandal (Department of Statistics, University of Manitoba), who informed the experimental design underpinning the elicitation exercises; and, Dr. Ryan Godwin (Department of Economics, University of Manitoba), who assisted in the analysis and interpretation of results.

DEDICATION

To Holly Fulford-Jeffrey, who furnished me with the tools I needed to invest in my own health. You were taken from us far too soon.

To my grandfather, David Rosenbaum, who was and is one of the wisest people I've ever met. I wish you could have been here to see this. I know you would have been very proud.

To my parents and brother, to whom I say simply this: everything I am and have accomplished is because of you. Let me be worthy of all your gifts.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

Acronym	Description
BMI	Body mass index
CANSIM	Canadian Socio-Economic Information Management System
CCDSS	Canadian Chronic Disease Surveillance System
CCHS	Canadian Community Health Survey
CHMS	Canadian Health Measures Survey
CIHI	Canadian Institute for Health Information
CIHR	Canadian Institutes of Health Research
CNF	Canadian Nutrient File
CPP	Canada Pension Plan
DHA	Docosahexaenoic acid
DP	Dynamic programming
DPoRT	Diabetes Population Risk Tool
DRI	Dietary reference intake
EER	Estimated energy requirements
eGFR	Estimated glomerular filtration rate
EI	Employment Insurance
EIA	Employment and Income Assistance
EPA	Eicosapentaenoic acid
EQ-5D	EuroQol 5D
GIS	Guaranteed Income Supplement
HbA_{1c}	Glycated hemoglobin
HDL/HDL-C	High-density lipoprotein cholesterol
HRQoL	Health-related quality of life
HUI	Health Utilities Index

Acronym	Description
Kcal	Kilocalories (unit of energy)
LDL-C	Low-density lipoprotein cholesterol
LPT	Lost productive time
LTPA	Leisure time physical activity
MAT	MATLAB file format
MDP	Markov decision process
MET	Metabolic equivalent of task
mmHg	Millimeter of mercury (unit of pressure)
MVPA	Moderate-to-vigorous-intensity physical activity
NHS	National Household Survey
OAA OR OAG	Oral antihyperglycemic agent
OAS	Old Age Security
PUFA	Polyunsaturated fatty acids
PUMF	Public Use Microdata File
PV	Present value
REE	Resting energy expenditure
SBP	Systolic blood pressure
SLID	Survey of Labour and Income Dynamics
T2DM	Type 2 diabetes mellitus
UKPDS	United Kingdom Prospective Diabetes Study
UKPDS-OM2	United Kingdom Prospective Diabetes Study Outcomes Model, Version 2
ZBK model	Zweifel, Breyer, and Kifmann model

GLOSSARY OF TERMS/CONCEPTS

Term	Definition
Absenteeism	Absence from the workplace due to illness. Depending upon the nature of the workplace, an employee experiencing illness may be remunerated for the days they are absent from work, although in Canada, there is generally no legal entitlement to paid sick days at either the federal or provincial level.
Action space	Within the context of a Markov decision model, the action space indicates what options are available to the decision-maker.
Adherence to leisure-time physical activity (LTPA)	In the context of this research, adherence to LTPA is defined as participation in $\geq$ 150 minutes per week of moderate-to-vigorous-intensity aerobic physical activity.
Adherence to healthy eating habits	In the context of this research, adherence to healthy eating habits is defined as consumption of a high-quality diet (itself defined with reference to the AHEI-2010) that may include a level of energy intake sufficient to achieve and sustain a healthy body weight.
Adherence to pharmacotherapy	In the context of this research, adherence to pharmacotherapy is defined as maintaining a sufficient supply of prescribed medications to avoid any lapses in treatment; it is assumed that individuals who maintain a regular supply of medication will in fact use them as directed by their physician.
Alternative Healthy Eating Index (AHEI) 2010	A 110-point dietary index that assesses the quality of an individual's nutritional intake according to the degree to which particular foods and nutrients are consumed in sufficient amounts (e.g., fruits and vegetables) or in moderation (e.g., trans fats).
Backward induction	In the context of dynamic programming (DP), backward induction is a technique for solving the Bellman equation, thereby identifying the optimal policy. The idea is that if the person knows that they will behave optimally regardless of

Term	Definition
	the circumstances they encounter, they can recursively work backward through the model to determine what course of action to take.
Bellman equation	In the context of DP, the Bellman equation states that the value function (i.e., maximum lifetime well-being from this point on) can be expressed as the largest possible sum of the reward (or within-period utility) enjoyed from the choice they make today and tomorrow's value function.
Body mass index (BMI)	Calculated by dividing weight (in kilograms) by the square of a person's height (in metres), BMI is often used to gauge the degree to which an individual is at risk for a range of health conditions. An individual with a BMI between 25 and 30 is generally categorized as overweight, while an individual with a BMI of 30 or greater is considered obese.
Canadian Nutrient File (CNF) 2015	The CNF-2015 is a computerized food composition database maintained by Health Canada that contains information on the nutrient in foods available in Canada. It is freely available to the public as an Access database.
Decision epoch	In the context of a Markov decision problem, a decision epoch refers to a point in time at which the individual observes the state they occupy, selects a course of action, and earns a reward (i.e., within-period utility). The choice made then influences which state they may occupy during the subsequent decision epoch.
Diabetes Population Risk Tool (DPoRT)	The DPoRT is a population-based risk prediction tool for incident diabetes which was developed from Canadian data sources. The model is driven by a series of validated equations that express the likelihood of developing T2DM as a function of a wide range of individual characteristics and risk factors, including gender, age, ethnicity, immigration status, level of educational attainment, BMI, current health status, and smoking behaviour.
Discount factor	The discount factor is a variable reflecting the degree to which people favour a unit of consumption in the present over a unit of consumption in the future (i.e., their rate of

Term	Definition
	time preference). A larger discount factor implies greater "patience" on the part of the individual.
Dynamic programming (DP)	DP is an approach to solving dynamic optimization problems developed by American mathematician Richard Bellman. Central to this approach are the Bellman Equation and the Principle of Optimality, which suggest one can solve such problems by breaking them down into more manageable sub-problems. DP is particularly well-suited to discrete-time optimization problems that incorporate stochasticity.
Energy balance	The difference between the number of calories consumed and expended (i.e., through physical exertion or maintenance the body's essential functions); people gain weight when the former exceeds the latter, and vice versa.
Health-related quality of life	Estimates of HRQoL are commonly incorporated into economic evaluations of health interventions, using data collected using such instruments as the EQ-5D, the HUI3, and the 36-Item Short Form Health Survey (SF-36).
Institute of Medicine equations	The Institute of Medicine equations predict an individual's estimated energy requirements (i.e., the level of caloric intake required to maintain a stable weight) by drawing upon information about their gender, height, weight, and level of physical activity.
Lost productive time (LPT)	The sum of days absent from work and the hour-equivalent of health-reduced performance at work.
Macrovascular complications	Complications resulting from diabetes that affect the body's large blood vessels, which include coronary artery disease (ischemic heart disease), peripheral arterial disease, and cerebrovascular disease (e.g., stroke).
Markov property	A property of a stochastic process whereby the likelihood of experiencing future states depends only on the current state and any action taken in the present.
Microvascular complications	Complications resulting from diabetes that affect the body's small blood vessels, which include retinopathy, neuropathy, and nephropathy.

Term	Definition
Model horizon	In the context of a Markov decision problem, this refers to the time frame over which decisions are being made.
Optimal policy	In the context of DP, the optimal policy is the strategy or sequence of actions that maximizes the value function over the model horizon.
Optimal transition matrix	In the context of DP, the optimal transition matrix indicates the probability of transitioning from one state to another when the individual adopts the optimal policy. Conceptually, one constructs the optimal transition matrix by splicing together the transition probability matrices associated with every element of the action space, such that the final product consists only of actions the individual would in fact take from each state.
Pharmacare Program	Administered by Manitoba Health, Seniors and Active Living, Manitoba's Pharmacare Program insulates the province's residents from the costs of medications on the Program formulary and is characterized by income-based deductibles beyond which all eligible costs are subsidized.
Preallocation	Pre-specifying how much memory is required for an array can improve the performance of MATLAB calculations, because it is computationally costly to incrementally increase the size of a data structure. When the array's contents are not known in advance, this can be achieved by declaring the size of the data structure and assigning zero values to each element; subsequent calculations can then replace these values as required.
Prediabetes	A state characterized by elevated blood glucose levels in which an individual is at higher risk of developing T2DM and may be accumulating damage to organs and tissues—although individuals with prediabetes may also be able to recover normal glucose regulation.
Presenteeism	Working while ill, which is often associated with reduced productivity.
Principle of Optimality	This principle states that the optimal policy to a DP problem should be characterized by time-consistency—that is, the

Term	Definition
	decision-maker should never have an incentive to revise any aspect of the policy.
Reward function	In the context of DP, the reward function specifies the reward or within-period utility an individual will enjoy from each possible choice, given the state they occupy.
Social determinants of health	Economic, social, or living conditions that affect health, including income and social status; social support networks; education; employment/working conditions; social environments; physical environments; personal health practices and coping skills; healthy child development; gender; and culture.
Sparse data structures	Sparse data structures are those that are mostly empty, storing only non-zero elements and their row indices. When data density is low, they can substantially reduce the amount of memory required for data storage and may also improve performance.
State dependence	In the context of health economic models, this refers to utility functions or production functions that depend upon an individual's current health state. In the context of this research, positive and negative state dependence refer to situations in which the marginal utility of consumption and leisure increase or decline as health deteriorates.
State space	In the context of DP, the state space refers to the range of possible circumstances in which decision-makers may find themselves.
Time preferences	Refers to how much individuals value current over future consumption. High rates of time preference imply "impatience", in that a relatively large return would be required to incent an individual to defray consumption.
Transition probability matrix	In the context of DP, the transition probability matrix indicates the likelihood of navigating between states. In Markov decision problems, these probabilities depend only on the state the individual presently occupies and the action they take in the current decision epoch.

Term	Definition
Type II diabetes mellitus	A progressive chronic disease characterized by the insufficient production of insulin and the body's inability to properly use insulin, which can manifest in a range of microvascular and macrovascular complications. Although genetic factors may predispose an individual to T2DM, many factors influence the risk an individual will develop it.
United Kingdom Prospective Diabetes Study Outcomes Model, Version 2 (UKPDS-OM2)	Licensed through the University of Oxford, the UKPDS-OM2 is a spreadsheet application implemented in MS Excel which draws upon data from the 30-year UKPDS to predict lifetime health outcomes and health care system costs for patients with T2DM. The model is driven by a series of validated risk equations that express the likelihood of a variety of clinical events as a function of a wide range of demographic and risk factors, as well as prior event history, and is designed to enable the user to simulate the impact of an existing or hypothetical T2DM intervention upon patients and health care system costs over years or decades.
Value function	In the context of DP, this function indicates the present value of expected utility an individual can realize by implementing the optimal policy—that is, the greatest level of well-being achievable, given the state they currently occupy.

Chapter 1: INTRODUCTION

This dissertation develops, validates, and demonstrates the application of a dynamic programming model in which rational, forward-looking decision-makers allocate scarce resources to maximize lifetime well-being, including making investments in health that can affect their chances of contracting type 2 diabetes mellitus (T2DM), and how the disease progresses. While many factors are known to influence the emergence and progression of T2DM, the model focuses specifically on choices relating to participation in physical activity and healthy eating habits, as well as to adherence to prescribed medications.

A central objective of this research is to model how T2DM affects labour market participation and performance, resource constraints, and health-related quality of life, and then to examine how awareness of these impacts by individuals drives optimal decision-making. I next illustrate how the model's results can be integrated into patient-level microsimulations to calculate the indirect economic costs attributable to deviation from fully rational, forward-looking health choices.

One important product of this research is a tool that demonstrates how the approach outlined in this thesis can be applied to calculate the potential for existing or hypothetical regulations, policies, programs and interventions to reduce costs to the Manitoba economy by encouraging better health-related decision-making. The framework outlined in this thesis is sufficiently flexible to support examination of initiatives designed to pursue a variety of policy objectives, such as management of health care expenditures and improved health-related quality of life. Although the tool has the potential to be of substantial interest to researchers and policymakers, it is critical to emphasize that it presently represents little more than a proof of concept requiring substantial additional development and investment before it can be meaningfully employed to inform or guide real-world decision-making.

Figure 1 outlines the content of the three core chapters of this thesis (i.e., excluding this introduction and Chapter 5, which concludes the dissertation) integrate the six key states of model development; this diagram will reappear periodically throughout the document to help the reader orient themselves:

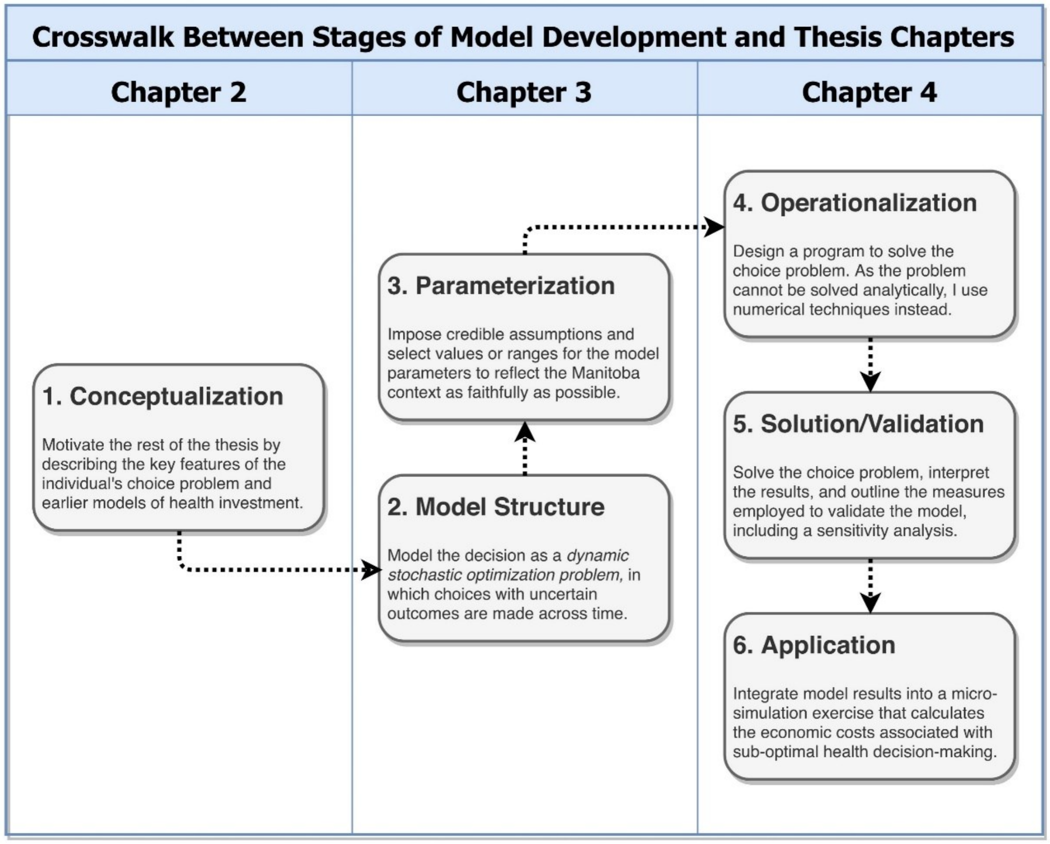

Figure 1: Overview of the dissertation

The first paper (Chapter 2) describes the clinical attributes of T2DM and the channels through which they impact individual well-being; identifying the modifiable and non-modifiable risk factors that contribute to the emergence and progression of these conditions, as well as the constraints individuals face in trying to reduce their risk of diabetes and its complications; and, surveying existing economic models and frameworks that could serve as the basis for the model or could contribute useful insights to facilitate its development.

T2DM is a chronic disease characterized by the body's inability to produce enough insulin or use it properly, resulting in damage to blood vessels, organs, and nerves that reduces average life expectancy and health-related quality of life, can adversely affect labour market participation, and may necessitate significant investments to help manage the condition. Several factors affect the likelihood of contracting T2DM and how quickly it progresses. Some of these factors, such as age and ethnicity, lie beyond the individual's control, while others, such as overweight/obesity and physical inactivity, can be influenced through choices individuals make regarding their eating habits, regularity of participation in exercise, and adherence to prescribed medications. However, constraints on time and income can make certain choices difficult or impossible.

Chapter 2 contrasts two existing models of the production of and demand for health, namely the Grossman model and the Zweifel, Breyer, and Kifmann ("ZBK") model (Grossman, 1972; Zweifel, 2012; Zweifel, Breyer, & Kifmann, 2009), and concludes that the objectives of this research can be best achieved through modification and extension of the ZBK model.

The second paper (Chapter 3) conceptualizes decision-making in the context of T2DM as an optimization problem situated within a finite-horizon, discrete time, discrete action/state Markov decision process model. People in the model transition through a series of states that reflect the aging process and the evolution of health and employment status. Some transitions, such as aging, occur with certainty, while others occur randomly. The individual can reduce—but not eliminate—the likelihood of experiencing T2DM by making prudent health-related choices (i.e., regular participation in physical activity, healthy eating habits, and adherence to pharmacotherapy, where applicable), but constraints on their time and income mean such choices may also limit their enjoyment consumption and leisure they are able to enjoy. Thus, the individual must decide whether expected increased future benefits, which may or may not manifest in any specific case, merit incurring certain short-term costs. Of note, decisions are assumed to be taken and transitions experienced on an annual basis; this simplifies the derivation of values for key model parameters, assists in managing the number of model states (and, by extension, greatly reduces computational burden), and may actually accord reasonably well with the frequency with which patients generally receive information salient for the purposes of guiding health-related or other decisions (e.g., annual physicals).[1]

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1 It is of course likely that the frequency of feedback will increase with the severity of a patient's condition due to increased vigilance by health care practitioners.

In addition, it is important to acknowledge that despite the observation that many if not most individuals with T2DM also suffer from one or more comorbidities (An, Le, & Dang, 2019; Finlayson, Ekuma, Yogendran, Burland, & Forget, 2010; Nowakowska et al., 2019), these are not modelled explicitly.[2] This was driven in part by gaps in the data required to extend the model in this manner, as well as by the realization that accommodating every possible combination of T2DM and its comorbidities, while certainly possible within the framework outlined here, would have dramatically increased the scale of data collection and parameter derivation activities, as well as the volume of computational resources required to initialize and solve the dynamic optimization problem and conduct microsimulations using the results.

A central feature of the model is its focus on the impact of T2DM on labour market participation and performance, and the implications this has for optimizing behaviour in the context of health-related decision-making. In particular, the model integrates findings from an emerging literature suggesting that T2DM

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2 It could be argued that the UKPDS-OM2 implicitly captures the impact of selected comorbidities upon the risk of diabetic complications and all-cause mortality through the incorporation of surrogate biomarkers (e.g., high LDL or SBP, which may reflect hyperlipidemia or hypertension, respectively) and key risk factors (e.g., presence of atrial fibrillation or history of heart failure) in the model's predictive risk equations. However, the model is not currently equipped to capture costs or health-related quality of life decrements associated with these comorbidities, nor is the list of comorbidities complete, excluding those such as asthma and depression which might be categorized as "discordant" (An, Le, & Dang, 2019; Piette & Kerr, 2006).

contributes significantly to workplace absenteeism and presenteeism and can accelerate work cessation (Lavigne, Phelps, Mushlin, & Lednar, 2003; Sørensen & Ploug, 2013).

The remainder of Chapter 3 adopts values or ranges for model parameters from a wide range of sources, including, but not limited to peer-reviewed and grey literature, Statistics Canada Public Use Microdata Files (PUMFs), predictive modelling undertaken using the Diabetes Population Risk Tool (DPoRT) 2.0 risk equations, simulation results generated with the United Kingdom Prospective Diabetes Study Outcomes Model Version 2 (UKPDS-OM2), and expert elicitation. In the instances where readily available parameter values do not exist, the model incorporates plausible ranges, which serve as the basis for the sensitivity analyses carried out in the subsequent chapter.

The third paper (Chapter 4) describes the implementation and illustrates the application of the model. It begins by describing how the model is operationalized through integration of programs developed in R, MATLAB, and Visual Basic for Applications. It also walks users through the application of the model, enumerating the specific steps required to solve the dynamic optimization problem, to carry out sensitivity analyses, and to design and implement simulations using optimal policies derived from the model. It concludes by demonstrating the correct the interpretation of results, using the default parameter values presented in Chapter 3.

The results suggest that, while mediated by an individual's characteristics and personal circumstances, the detrimental impacts of T2DM on well-being are usually enough to motivate fully-rational, forward-looking agents to act to reduce their risk of the condition and, among those who have been diagnosed, to take steps to manage it:

- Healthy individuals will usually try to minimize their risk of developing T2DM. Since the assumptions underlying the model imply they can achieve this through selective investments in health, they do so either by engaging in regular physical activity *or* adopting healthy eating habits—but not both), depending on how they value implied sacrifices of consumption and/or leisure these activities entail.

- People who already have T2DM will, similarly, take steps to manage its progression, but the results generated by the decision model indicate they accomplish this through selective health investments. In part, this reflects willingness to accept a higher risk of all-cause mortality or faster diabetic progression, in some cases, in return for more consumption or leisure. However, it also stems from the tendency for certain combinations of health-related activities to increase the risk of all-cause mortality among individuals with a history of micro- or macrovascular complications—a fate which, unsurprisingly, decision-makers are keen to avoid.

The second part of Chapter 4 focuses on the validation of the model. It begins by outlining the steps taken to ensure the programs functions as intended. It then examines the extent to which the results of the model are sensitive to the values of key parameters, including preferences over, and the elasticity of substitution between consumption and leisure; rates of time preference; productivity decline attributable to aging; and the relative costs of healthy and unhealthy eating habits. I also implement several robustness tests. The results of the sensitivity analysis align with expectations and suggest baseline parameter values are reasonable.

Chapter 4 concludes by demonstrating one of the model's potential policy applications. Consistent with this thesis' focus on the impact of chronic disease on labour market participation and performance, I investigate how productivity losses resulting from T2DM-driven workplace absenteeism, workplace presenteeism and premature mortality vary within a simulated cohort of 20,135 Manitobans who were 25 years of age on June 1st, 2017 when cohort members behave as the model predicts or adopt other patterns of health-related decision-making. The simulation results indicate that compared with the optimal strategy

- uniform adherence to all health behaviours is associated with indirect cost savings amounting to $46.6 M ($17.5 M in present value terms);

- uniform non-adherence to all health behaviours is associated with additional indirect costs amounting to $3,047.8 M ($1,345.3 M in present value terms);

- and, a strategy involving non-adherence while healthy and optimal adherence upon diagnosis with T2DM is associated with additional indirect costs amounting to $1,611.5 M ($702.4 M in present value terms).

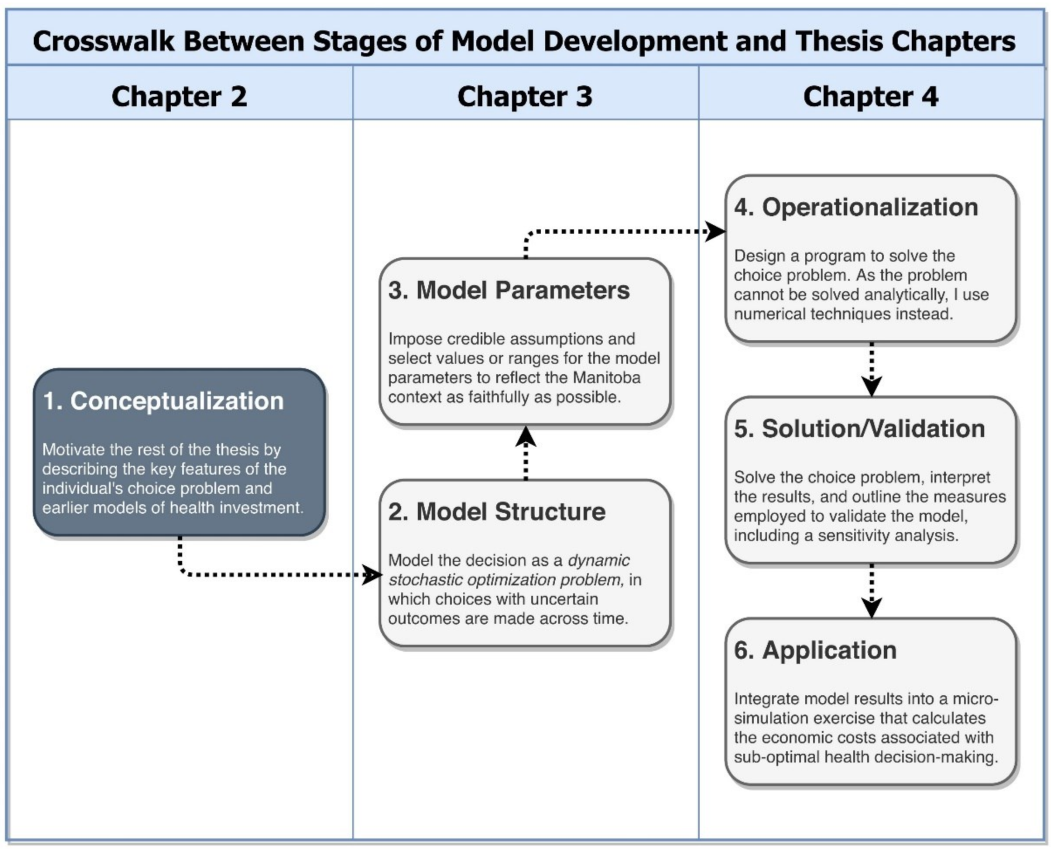
These results have several important policy implications. First, they suggest there is substantial scope to improve health and economic outcomes for Manitobans by implementing effective regulations, policies, programs and interventions that nudge individuals closer to optimizing behaviour. Second, significant efficiency loss reductions are achievable only by simultaneously acting both to prevent T2DM in those who are healthy or prediabetic, and to encourage appropriate management of the condition in those who have already been diagnosed. Finally, that individuals could have reduced efficiency losses still further but opted not to, suggests additional gains would be possible only by altering the structure of incentives within which their choices are made (e.g., to motivate some health-related choices and discourage others); it is unclear, however, whether the relatively small differences between the two scenarios are sufficient to merit such an intervention in the Province of Manitoba.

Chapter 5 concludes by summarizing the contributions of this thesis, the study's limitations and potential applications, and opportunities the thesis offers for future research in this area.

Chapter 2: LITERATURE REVIEW

1. INTRODUCTION

The goal of this research is to develop a model that predicts how fully rational, forward-looking economic agents make decisions that influence their risk of developing T2DM and experiencing its complications. This literature review grounds the thesis by furnishing the context necessary to characterize the optimization problem at its heart:



In particular, this chapter seeks to probe the following issues; as implied above, the answers to these questions will help me construct a framework for thinking about the decision-maker's problem that I will proceed to flesh out in Chapter 3:

1. What are the defining clinical attributes of T2DM (Section 2.1)? How does T2DM influence an individual's well-being (Section 2.2)?

2. What factors contribute to the emergence and progression of T2DM? Which of these can the individual influence (Section 2.3), and which lie beyond their control (Section 2.4)? What constraints does an individual face in trying to reduce their risk of T2DM and diabetic complications (Section 2.5)?

3. What existing economic models and frameworks can be used as the basis for the optimization problem, and what are the strengths and weaknesses of each approach (Sections 3.1 and 3.2)? How might these be adapted to achieve the objectives of this research, given what is known in relation to the questions outlined above (Section 3.3)?

2. TYPE II DIABETES (T2DM) IN CANADA

2.1 Overview of T2DM

2.1.1 Clinical Characteristics of T2DM

T2DM is a chronic disease characterized by the insufficient production of insulin and the body's inability to properly use insulin (Public Health Agency of Canada, 2011a, p. 7). T2DM tends to emerge in adults over the age of 40, particularly among individuals who are overweight or obese and/or physically inactive, although it is also increasingly presenting in children and adolescents (Canadian Diabetes Association, 2019a; Canadian Diabetes Association Clinical Practice Guidelines Expert Committee, 2013a, p. S163).

T2DM is distinct from type 1 diabetes mellitus, which is characterized by complete dependence on external sources of insulin, and which typically presents in people younger than 40. However, T2DM is estimated to account for more than 9 in 10 cases of diabetes in Canada (Public Health Agency of Canada, 2011a, p. 8). In addition, type 1 diabetes is strictly a genetic disorder; by contrast, although genetics may predispose some people to developing T2DM, the likelihood of onset appears, to varying extents, to be influenced by other factors, including individual lifestyle choices (Minor, 2011, p. 1469).

Prediabetes refers to a situation where blood glucose is elevated, though not to the levels typically observed in T2DM. Many individuals with prediabetes do not exhibit symptoms of the condition, but may begin to accumulate asymptomatic organ and tissue damage, and may be exposed to a higher risk of heart disease, stroke, and cardiovascular and all-cause mortality (American Diabetes Association, 2017b; Canadian Diabetes Association, 2013a, p. 2; Hsueh, Orloski, & Wyne, 2010; Y. Huang, Cai, Mai, Li, & Hu, 2016; Stumvoll, Goldstein, & van Haeften, 2005, p. 1333; Tabák, Herder, Rathmann, Brunner, & Kivimäki, 2012, pp. 2283–2284). Approximately 5-10% of people with prediabetes will progress to T2DM each year, with similar proportions reverting to normoglycemia (Tabák et al., 2012, p. 2279), and it is estimated that about half of Canadians with prediabetes will subsequently develop T2DM (Diabetes Québec & Canadian Diabetes Association, 2011, p. 8).

With the proper treatment and lifestyle changes, the medical consensus is that prediabetes can be reversed (Canadian Diabetes Association Clinical Practice Guidelines Expert Committee, 2013a, p. S9). By contrast, while T2DM can be managed through the appropriate combination of lifestyle changes and medical interventions, there is presently no cure. Furthermore, the progressive nature of T2DM (i.e., the gradual deterioration in the functioning of pancreatic β-cells) implies that treatment intensification is often necessary to sustain control of blood glucose levels (Fonseca, 2009).

2.1.2 Symptoms and Complications of T2DM

The classic symptoms of T2DM may include unusual thirst; excessive production of urine; weight loss or gain; excessive tiredness or fatigue; blurred vision; frequent or recurring infections; slow-healing cuts or bruises; tingling or numbness in hands or feet, and; sexual dysfunction (Canadian Diabetes Association, 2019a). However, because it is often asymptomatic in its early stages, which can last in excess of a decade (Rosella, Lebenbaum, Fitzpatrick, Zuk, & Booth, 2015, p. 1300), 20% or more of patients with T2DM present with complications upon diagnosis (Canadian Diabetes Association Clinical Practice Guidelines Expert Committee, 2013a, p. S61).

As just noted, increased levels of blood glucose in diabetics can damage blood vessels, organs, and nerves, manifesting in complications such as, but not limited to vision loss, loss of sensation in and potential amputation of extremities, chronic kidney disease, heart disease, and stroke (American Diabetes Association, 2017c; Fowler, 2008; Public Health Agency of Canada, 2011a, pp. 31–32; Slade, 2012, p. 502). Diabetes itself does not typically lead directly to death, but its complications do (Jungwee & Peters, 2014, p. 15). Indeed, cardiovascular disease is the leading cause of death among diabetics (Fowler, 2008, p. 80; Public Health Agency of Canada, 2011a, pp. 31–32). In addition, diabetic complications can significantly reduce an individual's quality of life and their capacity to participate and perform in the labour market—issues to which I return in Sections 2.2.2 and 2.2.3, respectively.

2.1.3 Prevention and Management of T2DM

Preventing T2DM

Several large-scale studies undertaken over the past two decades have demonstrated the potential for lifestyle interventions (possibly supplemented by pharmacotherapy) to prevent or delay progression to T2DM (see Section 2.3.1 below for an overview of these studies). Current Canadian guidelines therefore recommend that patients with impaired glucose tolerance, impaired fasting glucose, or HbA_{1c} levels between 6.0-6.4% engage in "structured [programs] of lifestyle modification that [include] moderate weight loss and regular physical activity", adding that treatment with metformin or acarbose may be used to further reduce the risk of T2DM (Canadian Diabetes Association Clinical Practice Guidelines Expert Committee, 2013a, p. S18). In addition, smoking cessation and adoption of healthy and balanced diets are generally regarded as important steps for delaying or preventing the onset of T2DM.

Screening for and Diagnosis of T2DM

Current Canadian guidelines recommend screening for T2DM every three years in individuals aged 40 or older or in high-risk individuals; screening is undertaken using a fasting plasma glucose test or through measurement of glycated hemoglobin (HbA_{1c}) levels (Canadian Diabetes Association Clinical Practice Guidelines Expert Committee, 2013a, pp. S12–S14). More frequent and/or earlier testing may be warranted in individuals considered to be at especially high risk (Canadian Diabetes Association Clinical Practice Guidelines Expert Committee, 2013a, p. S192).

Treatment Modalities

Current Canadian guidelines emphasize the role of lifestyle modification in managing T2DM and, in fact, suggest that pharmacotherapy should only be introduced when lifestyle interventions are insufficient to manage blood glucose levels (Canadian Diabetes Association Clinical Practice Guidelines Expert Committee, 2013a, p. S61). However, T2DM is a progressive disease that gradually erodes the body's capacity to produce insulin; as a consequence, pharmacotherapy is likelier to become necessary the longer a person lives with the condition (Public Health Agency of Canada, 2011a, p. 28). Furthermore, while oral antihyperglycemic agents (OAGs) are appropriate in the early stages of the disease, in many cases it will become necessary to transition to injectable insulin over time.

Because T2DM places patients at significantly increased risk of macrovascular events, current guidelines also strongly encourage measures that promote vascular protection (i.e., management of cholesterol and blood pressure in addition to achieving satisfactory blood glucose levels), which again consists of a combination of lifestyle modification and pharmacotherapy (Campbell et al., 2011; Canadian Diabetes Association Clinical Practice Guidelines Expert Committee, 2013a, pp. S101, S110).

In addition to being a key component of vascular protection strategies (Canadian Diabetes Association, 2013b), smoking cessation is generally considered a critical component of diabetes management, since the combination of high blood glucose and exposure to the substances found in cigarettes can accelerate the development and progression of diabetic complications (Canadian Diabetes Association, 2013c; Public Health Agency of Canada, 2011a, p. 65). Smoking cessation typically relies to significant extent on a patient's own willpower and desire to quit, although nicotine replacement therapy and medication may maximize their likelihood of success (Canadian Diabetes Association, 2013c).

Additional health care interventions are typically required to detect and address diabetic complications. Due to their substantial impacts on patients' quality of life (see Section 2.2 below) and costs to the health care system, it is imperative that the emergence of diabetic complications be detected and treated in a timely manner. This, in turn, requires vigilance on both the part of health care practitioners and their patients.

As the foregoing discussion implies, lifestyle changes initiated and sustained by individual patients—including smoking cessation, adoption of a healthy diet (including moderating consumption of alcohol), frequent exercise, and weight loss (Slade, 2012, p. 503) constitute a critical component of efforts to delay, prevent, and manage T2DM.

2.2 Impact of T2DM on Patient Well-Being

This section is to review previous research describing the impact of the development and progression of T2DM on individuals and households in Canada.

2.2.1 Impact on Life Expectancy

On average, individuals with T2DM have an average life expectancy approximately 5-15 years less than non-diabetics (Canadian Diabetes Association, 2016a, p. 40), largely due to premature excess mortality from macrovascular complications (Laakso, 1999, p. 937; Orbell & Hagger, 2006, p. 537). A small number of Canadian studies have also linked diabetes mellitus to significantly reduced health-adjusted life expectancy (i.e., the average time an individual can expect to live in full health) (Loukine, Waters, Choi, & Ellison, 2012; Manuel & Schultz, 2004; Sikdar, Wang, MacDonald, & Gadag, 2010).

2.2.2 Impact on Health-Related Quality of Life (HRQoL)

Many studies conducted both in Canada and other jurisdictions have examined the impact of T2DM on patients' quality of life. In general, the results suggest that individuals with this condition experience lower HRQoL than others; furthermore, patients with diabetes-related complications are typically found to have lower HRQoL than patients with no complications (Alva, Gray, Mihaylova, & Clarke, 2014; Coffey et al., 2002; E. S. Huang, Brown, Ewigman, Foley, & Meltzer, 2007; Maddigan, Feeny, & Johnson, 2005; O'Reilly et al., 2011; Sikdar et al., 2010). Patient welfare may also be significantly influenced by treatment modality (Bailey & Kodack, 2011; Boye et al., 2010; Coffey et al., 2002; Harris et al., 2014; E. S. Huang et al., 2007; Polonsky & Henry, 2016; Tiktin, Celik, & Berard, 2016; Vijan, Sussman, Yudkin, & Hayward, 2014; Walz et al., 2014).

2.2.3 Impact on Labour Force Participation and Performance

In general, diabetes does not in itself significantly affect an individual’s ability to perform most activities in the majority of workplaces, although there are exceptions (American Diabetes Association, 2012, pp. S94–S95; Canadian Diabetes Association, 2017; Kraut, Walld, Tate, & Mustard, 2001, p. 64). Individuals with T2DM who are not experiencing complications may nonetheless require relatively modest accommodation from their employers to help manage their condition (e.g., being allowed regular breaks to eat, monitor blood sugar or administer medication) (Canadian Diabetes Association, 2017).

Some diabetic complications may affect an individual’s capacity to perform certain tasks. As an example, employees with diabetic foot disease may find it challenging to perform activities that involve walking or prolonged periods of standing (Waters & Holloway, 2009, p. 34). Individuals experiencing complications from diabetes may also require special accommodation in the workplace (American Diabetes Association, 2012, p. S97).

There is a growing empirical literature documenting the impact of T2DM on specific aspects of labour force participation and performance; broadly speaking, the evidence suggests T2DM significantly affects labour supply and performance, including decreased probability of employment, increased absenteeism, reduced on-the-job productivity (i.e., presenteeism), and earlier work-cessation due to retirement or mortality.

Employment status

On the basis of a prospective, population-based cohort study of 26,162 working-age Manitobans, Kraut, Walld, Tate, and Mustard (2001) find that diabetics with complications are twice as likely not to be in the labour force than other Manitobans, although no increased risks are identified for other diabetics. Among other things, these results suggest that the severity of T2DM mediates the condition's impact upon labour force outcomes, which is consistent with the observation that T2DM itself does not significantly impair labour market performance. Ng, Jacobs, and Johnson (2001) offer support for this theory through their analysis of 1989 National Health Interview Survey data, observing that whereas diabetes itself reduces the likelihood of being in the labour force by about 3.6%, the presence of diabetic complications did so by 12.4% (p. 259).

Latif (2009) uses data from Cycle 3 of Canada's National Population Health Survey (1998-1999) to examine the impact of diabetes on employment in Canadians aged 15-64, addressing endogeneity in the employment decision by employing a recursive bivariate probit model.[3] He finds that while there are significantly lower levels of employment among individuals with diabetes, after accounting for endogeneity, the impact of diabetes on employment in males is statistically insignificant; by contrast, diabetes is found to have a negative impact on female employment (p. 585).

Wang (2010) similarly uses data from the CCHS for years 2007-2008 to investigate how diabetes influences employment status in Canadians aged 30-64. Similar to Latif (2009), Wang (2010) estimates a series of probit models, but appears not to have attempted to control for endogeneity. Upon regressing the probability of employment on a vector of observable characteristics that includes diagnosis with type 1 or type 2 diabetes, Wang (2010) finds that T2DM is associated with a significantly lower probability of employment in both men (a reduction of 9.55%, relative to non-diabetics) and women (6.33%) (pp. 16-17).

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3 Some studies examining the relationship between diabetes and employment status warn against merely assuming the presence of diabetes to be an exogenous variable, arguing that failing to account for endogeneity runs the risk of yielding biased coefficient estimates. Endogeneity could be present if, for example, labour force status impact health, as might occur if being unemployed results in the adoption of unhealthy behaviours that lead to development of T2DM or limits opportunities to expend calories (H. S. Brown, Pagán, & Bastida, 2005, p. 539), or if the nature of one's work influences T2DM risk (Buxton et al., 2012; Gallagher, 2014; Gan et al., 2014). Alternatively, unobserved factors such as personal motivation could drive both the likelihood of gainful employment as well as health-related decision-making that impact the probability of developing T2DM (Latif, 2009, p. 578).

However, after controlling for other chronic conditions, T2DM reduces employment only in men (7.82%) (pp. 18-20).

A number of other studies confirm the negative influence of diabetes on employment status, including Fletcher and Richards (2012), Brown, Pagán, and Bastida (2005), Minor (2011), and Yassin, Beckles, and Messonnier (2002).

Although T2DM may negatively affect the probability of employment, the literature does not clearly support the hypothesis that individuals with the condition are more likely to be *unemployed*. For instance, Kraut, Walld, Tate, and Mustard (2001) observe that even Manitobans experiencing diabetic complications are not obviously more likely to be unemployed than nondiabetic individuals, leading them to conclude that people within the former group who leave their jobs may choose to withdraw from the labour force and not seek other work (p. 67). Other empirical studies have reached similar conclusions (Alavinia & Burdorf, 2008; Rodríguez-Sánchez & Cantarero-Prieto, 2017).

Absenteeism and presenteeism

Absences from work can result either from increased need for sick time, or from a diversion of available hours towards either receiving health care services or to lifestyle modifications aimed at halting or slowing the progression of the disease.

Numerous studies have identified an association between T2DM and increased absences from work. For example, on the basis of a review of eight previous studies, Breton et al. (2013) conclude that individuals with diabetes have between 5.4 and 18.1 days of absenteeism per year, compared with 3.4 to 8.7 days for individuals without diabetes, implying that the excess burden of absenteeism attributable to this illness is roughly 2-10 days annually.

These values may, however, conceal substantial variability among T2DM patients attributable to microvascular and macrovascular complications, or comorbidities. By way of illustration, Sørensen and Ploug (2013) find that the emergence of diabetic complications has the potential to substantially increase work-loss days, especially in the year the complication is experienced; for instance, they note that heart failure is associated on average with 73.0 additional days of work absence in the year the event occurs (compared to those without heart failure), but only 6.1 days in subsequent years (p. 6).

Reduced on-the-job productivity stemming from chronic disease is often referred to as presenteeism (Koopman et al., 2002). A small number of studies has attempted to estimate on-the-job productivity losses associated with diabetes, although in interpreting and comparing their results it should be noted that they do not necessarily apply a uniform methodological approach.

Lavigne, Phelps, Mushlin, and Lednar (2003) recruited 472 patients in New York State to examine the impact of T2DM on workplace productivity, of whom 78 had been diagnosed with the disease (p. 1125). The authors estimate efficiency losses stemming from T2DM as the product of the number of days the individual worked while unwell, the hours per day over which he or she experienced symptoms, the reduction in efficiency occurring during this time, and the individual's hourly earnings. Tobit regressions were selected to model work efficiency losses, total productivity time lost and the value of that time, because data were continuous but censored (p. 1126). They find that although T2DM itself does not significantly influence efficiency losses incurred by individuals in the sample, efficiency is reduced by the equivalent of about one hour per month for each year elapsed since diagnosis (p. 1129), which could conceivably reflect the gradual onset of microvascular and macrovascular complications. The authors conclude that although diabetes significantly reduced work productivity in those suffering from the disease, productivity losses relative to non-diabetics were minor because of lower earnings among the former; they suggest that the market had partly accounted for the lower productivity of these individuals through adjustments to their wages (p. 1132).

Synthesizing the results of five large-scale workplace surveys, Goetzel et al. (2004) estimate that presenteeism generates an 11.4% reduction in productivity (expressed as the percent of eligible work time available per year) among diabetics relative to non-diabetics. Additionally, Stewart, Ricci, Chee, Hirsch, and Brandenburg (2007) investigate lost productive time (LPT) attributable to both absenteeism and presenteeism among 19,075 working adults in the US population, including 1,003 reporting a physician diagnosis of diabetes, of whom 391 were experiencing symptoms of diabetic neuropathy. They ascertain that although mean total hours of LPT per week are similar for non-diabetics and diabetics not affected by neuropathy (1.92 and 1.91 crude hours per week, respectively), they are substantially higher among those reporting neuropathic symptoms (4.21 hours per week). Presenteeism accounted for about two-thirds (66%) of the LPT among respondents with diabetes (p. 677).

Finally, in compiling their estimate of the economic costs of T2DM for the United States, the American Diabetes Association (2008, 2013) adapts the results of the Goetzel et al. (2004) study to account for the proportion of hypertension not attributable to diabetes, concluding on this basis that diabetes is associated with a productivity loss of 6.6%, equivalent to 14 days per worker per year (p. 603).

Work Cessation

Individuals with T2DM might deliberately exit the labour force earlier than would otherwise occur if their condition and/or its complications and comorbidities result in reduced productivity, causing wages to slip beneath the reservation level (Laitner & Sonnega, 2012; Latif, 2009, pp. 578–579), particularly if they are able to access alternatives sources of income, such as the Canadian Pension Plan (CPP), Old Age Security (OAS), and the Guaranteed Income Supplement (GIS) (French, 2005)**.** They might also become physically incapable of working due to disability or might die prematurely (e.g., especially because of macrovascular complications).

Many studies have studied the relationship between T2DM and work cessation; the results of these studies suggest that T2DM may result in workers exiting the labour force prematurely (Adepoju et al., 2014; Alavinia & Burdorf, 2008; Chatterji, Joo, & Lahiri, 2016; Herquelot, Guéguen, Bonenfant, & Dray-Spira, 2011; Rumball-Smith, Barthold, Nandi, & Heymann, 2014; Vijan, Hayward, & Langa, 2004).

2.3 Modifiable Risk Factors Contributing to T2DM Development and Progression

Patients can reduce their risk of developing T2DM and the rate at which it progresses in several ways, including lifestyle choices and adherence to prescribed medications.

2.3.1 Contribution of Individual Lifestyles

T2DM is often described as a "lifestyle disease", in the sense that it is commonly associated with specific choices around dietary intake and participation in physical activity (American Academy of Family Physicians, 2011, p. 8; Diabetes Québec & Canadian Diabetes Association, 2011; Hofmann, Hjelmesæth, & Søvik, 2013; C. S. Ng, Lee, Toh, & Ko, 2014; Poulsen, Cleal, & Willaing, 2014). Several large-scale studies undertaken over the past two decades, including the Malmö feasibility study, the Finnish and US Diabetes Prevention Studies, and the Da Qing Diabetes Prevention Study have demonstrated the potential for lifestyle interventions (possibly supplemented by pharmacotherapy), to prevent or delay progression to T2DM (Horton, 2009, p. S44; Qiao, Williams, Imperatore, Narayan, & Tuomilehto, 2015, p. 43).

Dietary Intake

There is strong evidence that an individual's diet can influence their risk for developing T2DM, as well as its progression.

Overall caloric intake is associated with the likelihood of T2DM in that overweight and obesity, which is a known risk factor for diabetes, can result from a positive energy balance (refer to the discussion on page 33 below). Managing nutritional intake so as to achieve a more favourable balance is therefore an important component of T2DM prevention and management (Mann & Chisholm, 2015, p. 577).

However, the composition of an individual's diet is also important, especially in addressing other diabetic risk factors, such as high blood pressure and/or high cholesterol (Public Health Agency of Canada, 2012), which may be only partly correlated with a person's overall energy intake. While there appears to be no clear consensus as to precisely what constitutes an optimal diet for T2DM prevention and management, it seems generally accepted that people should moderate intake of alcohol, sodium, red or processed meats, refined grains, sugar-sweetened beverages and saturated and trans fats, while ensuring ample consumption of fruit, vegetables, whole grains, and nuts and legumes (Ajala, English, & Pinkney, 2013; Canadian Diabetes Association Clinical Practice Guidelines Expert Committee, 2013c; Chiuve et al., 2012; Evert et al., 2014; Ley, Hamdy, Mohan, & Hu, 2014; Mann & Chisholm, 2015, p. 577; Qiao et al., 2015; Salas-Salvadó, Martinez-González, Bulló, & Ros, 2011).

Physical Activity

Physical activity plays an important role in the prevention and management of T2DM by facilitating weight management, promoting glycemic control, and lowering blood pressure (Canadian Diabetes Association, 2012, p. 2; Canadian Diabetes Association Clinical Practice Guidelines Expert Committee, 2013d, p. S40; Garvey & Arathuzik, 2016, p. 235; Qiao et al., 2015, pp. 42–43; Warburton, Nicol, & Bredin, 2006, pp. 42–43).

The Canadian Society for Exercise Physiology (2013) recommends that adults engage in 150 minutes of moderate-to-vigorous aerobic physical activity per week in bouts of 10 minutes or more, supplemented wherever possible by at least two days of muscle and bone-strengthening activities (pp. 9-10). The Canadian Diabetes Association Clinical Practice Guidelines Expert Committee (2013d) has issued similar recommendations for individuals with T2DM, adding that "a structured program of lifestyle modification that includes moderate weight loss and regular physical activity" be implemented to reduce the risk of T2DM in individuals with impaired glucose tolerance and impaired fasting glucose (Canadian Diabetes Association Clinical Practice Guidelines Expert Committee, 2013e, p. S16).

Humphreys, McLeod, and Ruseski (2014) apply a recursive bivariate probit model to data from Cycle 3.1 of the Canadian Community Health Survey (CCHS) in order to estimate partial marginal effects of leisure time physical activity (LTPA) on health outcomes; they determine that a transition from inactivity to moderate physical activity reduces the risk of developing T2DM by 8.5 percentage points (p. 43-44)—although other research suggests work-related physical activity, but not LTPA, reduces the probability of developing diabetes (2014). In addition, Lee et al. (2012) estimate that physical activity is responsible for approximately 7.0% of the burden of disease associated with T2DM in Canada (p. 223). By contrast, Katzmarzyk (2011) places this figure at 19.8% (p. 35).

A growing body of evidence suggests physical inactivity and sedentary behaviour constitute distinct risk factors for a range of chronic diseases. In particular, extended periods of sedentary behaviour may adversely affect health even if a person is otherwise highly active (Canadian Fitness and Lifestyle Research Institute & ParticipACTION, 2013; Colley et al., 2011, p. 2; Nicholas et al., 2015; Qiao et al., 2015, pp. 42–43; Sarma, Devlin, et al., 2014).

Overweight and Obesity

Overweight and obesity result when an individual's ingestion of calories exceeds the calories they expend through physical exertion, a condition described as positive energy balance (J. O. Hill, Wyatt, & Peters, 2012). Overweight and obesity is typically defined in terms of body mass index (BMI), which is calculated by dividing weight (in kilograms) by the square of a person's height (in metres). An individual with a BMI between 25 and 30 is generally categorized as overweight, while an individual with a BMI of 30 or greater is considered obese (Public Health Agency of Canada, 2011a, p. 54).

Overweight is widely regarded as a significant modifiable risk factor for T2DM (Canadian Diabetes Association, 2019b; Qiao et al., 2015, p. 42; Rogers & Still, 2005; Rosenthal, 2009, p. 27; Wilding, 2014), and more than three-quarters of Canadians with diabetes are classified as overweight or obese (Public Health Agency of Canada, 2011a, p. 58; Wilding, 2014).

Reducing weight by even a relatively small proportion can significantly affect an individual’s risk of T2DM (Canadian Diabetes Association, 2013a, p. 2; Mayo Clinic Staff, 2017); for example, it is estimated that losing 5-7% of one’s body weight can reduce the likelihood of prediabetes by half (American Heart Association, 2017). Additionally, modest weight loss in patients with T2DM has been shown to improve risk factors associated with the emergence of diabetic complications (Canadian Diabetes Association Clinical Practice Guidelines Expert Committee, 2013f, p. S83). Overweight and obesity can often be managed through a combination of dietary changes and initiation or intensification of regular physical activity; however, pharmacotherapeutic and surgical interventions may also be appropriate in some circumstances (Canadian Diabetes Association Clinical Practice Guidelines Expert Committee, 2013f, pp. S84–S85).

Smoking

Smoking is strongly associated with increased risk for T2DM (Chang, 2012, p. 399; Maddatu, Anderson-Baucum, & Evans-Molina, 2017; Qiao et al., 2015, pp. 44–45; Rosenthal, 2009, p. 28), with the Office of the Surgeon General (2014) concluding that the risk of diabetes is 30-40% higher for active smokers relative to non-smokers. The evidence moreover suggests that smoking significantly increases the risk of diabetic complications (Chang, 2012; Rosenthal, 2009, p. 28; US CDC, 2017a). For this reason, smoking cessation is regarded as an important objective in reducing the risk of developing T2DM, or in preventing or delaying complications among individuals who already have the condition (Canadian Diabetes Association, 2013c).

2.3.2 Contribution of Adherence to Pharmacotherapy

Numerous recent studies have found a link between adherence to pharmacotherapy and health outcomes in the context of T2DM. For example, Jha, Aubert, Yao, Teagarden, and Epstein (2012) find that improved adherence (i.e., having supplies of medication 80% of the time in 2007 despite not being nonadherent in the preceding year) to pharmacotherapy reduced the odds of subsequent hospitalizations and emergency room visits by 13% within a sample of US patients with a formal diagnosis of diabetes. Similarly, after controlling for confounding factors, Currie et al. (2012) conclude that non-compliance with pharmacotherapy and non-attendance at appointments with health care practitioners independently increased the risk of all-cause mortality in type 2 diabetics in a sample of 15,984 patients in general practices in the UK.

Several studies have also examined the relationship between medication adherence and risk factors known to be associated with increased risk of microvascular and macrovascular complications, such as HbA_{1C} and LDL-C (Aikens & Piette, 2013; Asche, LaFleur, & Conner, 2011; Egede, Gebregziabher, Echols, & Lynch, 2014; Pladevall et al., 2004; Schectman, Nadkarni, & Voss, 2002). Briefly, results from these studies suggest an inverse relationship between adherence and risk factors, especially HbA_{1C}.

2.4 Non-Modifiable Risk Factors Contributing to T2DM Development and Progression

Although individuals can act to address many factors that influence their risk of experiencing T2DM and its complications, other factors may lie largely or entirely outside the patient's control.

2.4.1 Contribution of Age

The risk of developing T2DM increases with age, particularly after age 40 (American Heart Association, 2017; Mayo Clinic Staff, 2017; Rosenthal, 2009, pp. 29–30), although some evidence suggests it may begin to level off at older ages (Dall et al., 2010, p. 299; Kirkman et al., 2012, p. 2650; Public Health Agency of Canada, 2011a, pp. 15, 19–20; Statistics Canada, 2017e, p. 3).

2.4.2 Contribution of Genetics and Ethnicity

There is strong evidence of a genetic basis for T2DM (Stumvoll et al., 2005); for example, the lifetime risk of developing T2DM is about 40% if one parent suffers from the condition, and approximately 70% if both parents do (Groop et al., 1996; Lyssenko & Laakso, 2013, p. S120). Genome-wide association studies have so far identified dozens of independent single-nucleotide polymorphisms that increase the risk of developing T2DM (Dorman et al., 2009; Miguel-Yanes et al., 2011; Talmud et al., 2015; Vassy et al., 2012). However, the genetic variants identified to date have performed poorly in explaining variance in disease risk (McCarthy, 2010, p. 2342; Talmud et al., 2015, p. 1831), supporting the hypothesis that it is not merely genes but the interaction between genes and the environment that is generally responsible for the development of T2DM (Lyssenko & Laakso, 2013, p. S120; Rosenthal, 2009, pp. 30–31).

It is well-known that certain ethnic groups are more susceptible to developing T2DM than others, including individuals of South Asian, Hispanic American, Chinese, and African ancestry, as well as Indigenous Peoples (i.e., First Nations, Inuit and Métis) (Canadian Diabetes Association, 2019b; Public Health Agency of Canada, 2011a, pp. 69, 93–94). Ethnicity may also mediate the relationship between weight and the risk of T2DM, with some studies finding that ethnic minorities commonly develop the condition at significantly lower BMIs than their Caucasian counterparts (Chiu, Austin, Manuel, Shah, & Tu, 2011; Zhu et al., 2019). Although differences in the distribution of genetic risk across different racial and ethnic groups may partially drive these observations, some authors have warned against understating the contributions of cultural factors (e.g., to the extent these may influence dietary preferences) or environmental or socioeconomic considerations (Curry, 2017; Pearce, Foliaki, Sporle, & Cunningham, 2004; Taylor, Spencer, Mahabaleshwarkar, & Ludden, 2017).

The complexity of these relationships is best exemplified by efforts to explain the high prevalence of obesity and T2DM among Canada's Indigenous Peoples. A review of the current literature suggests this is attributable not merely to genetic predisposition to the illness, but also to the confluence of socio-economic factors, barriers to care, and the relatively recent proliferation of processed foods high in calories, saturated fats and simple sugars (Canadian Diabetes Association Clinical

Practice Guidelines Expert Committee, 2013a, p. S191; Ghosh & Gomes, 2011, p. 297; Hegele, Cao, Harris, Hanley, & Zinman, 1999; Public Health Agency of Canada, 2011a, pp. 93–94).[4]

2.4.3 Contribution of Variability in Access to and Quality of Medical Care

Access to health care services may be affected by several factors:

- *Geography.* Residents in remote, northern and Indigenous communities may find it difficult to acquire the same range and quality of health care services that are readily available in larger population centres (Canadian Diabetes Association, 2016a, p. 27; Ghosh & Gomes, 2011, p. 266; Hudson, 2011, pp. 224–225; Reid et al., 2006, p. 1071). This is significant given that individuals with T2DM are, on average, more intensive users of health services than the general public, and may be particularly reliant on the availability of specialty services (Canadian Diabetes Association, 2016a, p. 27).

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4 The "thrifty gene hypothesis" posits that Indigenous Peoples are genetically predisposed to conserve calories as a result of the hunter-gatherer lifestyle their ancestors led prior to contact with Europeans; however, the theory is controversial (Latif, 2009, n. 1; Public Health Agency of Canada, 2011a, pp. 93–94; Richards & Patterson, 2006, p. 542; Rosenthal, 2009, pp. 31–32; Unger, 2012, p. 554).

- *Household circumstances.* Individuals in lower-income households might have less contact with their primary care provider or other parts of the health care system, due, for example, to poor access to transportation, or to limited control over working conditions (Canadian Medical Association, 2013; Zhang et al., 2009, p. 100). Although Canada's health system ensures coverage for medically necessary hospital and physician services, this does not extend to many other products and services commonly required by individuals with T2DM, such as vision, dental and psychological care, prescription drugs, and visits to chiropodists/podiatrists (Canadian Diabetes Association, 2016a, p. 27; Health Canada, 2016b). While some jurisdictions administer programs that can help to insulate households from these expenses, patients with T2DM are often required to bear at least some proportion of the associated costs, which may place substantial strain on household finances and discourage use.

- *Variability in screening for T2DM.* Early detection of T2DM better equips patients and their physicians to plan and implement interventions that increase the likelihood of being able to delay or prevent T2DM, or, failing that, to slow its progression. However, on the basis of an analysis of data collected through the 2015 Canadian Health Measures Survey (CHMS), the Canadian Diabetes Association (2016a) reports that whereas 32% of people without diabetes indicated having been screened for the condition at least once a year, this occurred less frequently for 21% of respondents, and 34% had never been screened for the condition (p. 23). While those aged 45 years or over were more likely to report annual screening for T2DM, a sizable proportion of this subset of respondents have rarely if ever been tested.

- *Variability in screening for diabetic complications and associated risk factors.* Given the substantial quality of life impacts associated with diabetic complications (see Section 2.2.2 above), and the costs their treatment imposes upon taxpayers (Goeree et al., 2009; Hopkins, Burke, Harlock, Jegathisawaran, & Goeree, 2015), frequent screening for complications and constant monitoring of risk factors is essential. However, data from the 2007 CCHS indicates that although 81% and 74% of the adult population with T2DM had had an HbA_{1c} test and urine protein test in the previous year, respectively, two-thirds (66%) had received a dilated eye exam, half (51%) had had their feet checked by a health care professional, and just under one-third (32%) had received all four care components (CIHI, 2009, p. 8).[5]

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[5] Analysis of the CCHS data further reveals a significant socio-economic gradient, with diabetes patients with annual household income of $60,000 being twice as likely to receive all four recommended tests as those with household income less than $20,000 (42% versus 21%) (p. 17).

- *Discrimination and linguistic/cultural barriers.* Discrimination and linguistic/cultural barriers may hinder access to care and compromise both the quality of services delivered as well as patient safety. for example, health care practitioners who do not fully understand a patient's health concerns may resort to unnecessary tests, make incorrect diagnoses, and/or recommend inappropriate interventions (Health Canada & Public Health Agency of Canada, 2017, p. 10).

2.4.4 Contribution of Social Determinants of Health

Social determinants of health may be defined as "the economic and social conditions, or living conditions, that shape our health" (Raphael, 2011, p. 7). Key Social determinants of health include: income and social status; social support networks; education; employment/working conditions; social environments; physical environments; personal health practices and coping skills; healthy child development; gender; and culture (Public Health Agency of Canada, 2015). Characterizing T2DM as a lifestyle disease has the potential to be misleading in that it fails to acknowledge a range of non-modifiable factors that increase the risk of developing diabetes, including factors that constrain individuals' and households' lifestyle choices (J. Hill, Nielsen, & Fox, 2013, fig. 1; Public Health Agency of Canada, 2011a, p. 71). Indeed, proponents argue that these determinants are no less important than household health behaviours (Alvaro et al., 2011; PharmaWatch Canada, 2012; Raphael, 2011, p. 11).

This research relates primarily with health-related behaviours and is thus concerned with social determinants of health only insofar as they influence or constrain behaviour or confound efforts to isolate the impact of behaviour on health outcomes. That said, it is important to acknowledge previous and ongoing research findings which, taken together, suggest that social determinants of health contribute significantly to the incidence and prevalence of T2DM in Canada.

2.5 Constraints on Health-Related Decision-Making

While the discussion in Section 2.3 above suggests significant scope for individuals to reduce the risk of T2DM and/or slow the progression of diabetes through careful health-related decision-making, constraints on time and income may affect their ability to do so.

2.5.1 Cost of maintaining a healthy diet

Canada's Food Guide describes a healthy diet as one incorporating an acceptable balance of fruit, vegetables, and grain, dairy and meat products (or appropriate alternatives), and that limits consumption of foods and beverages high in calories, fat, sugar, and/or salt (Health Canada, 2011). As discussed in Sections 2.1.3 and

2.3.1 above, it appears generally accepted that sustaining a healthy diet can reduce an individual's risk of T2DM and of experiencing diabetic complications—though the optimum composition of such a diet seems to be an open question at the present time (Ajala et al., 2013).

However, maintaining a healthy diet can be costly. For example, Jetter and Cassady (2006) find that the average cost of the US Department of Agriculture's Thrifty Food Plan is approximately 15.7% lower than a basket consisting of healthier alternatives—an amount equal to approximately 35-40% of a low-income consumer's annual food budget. Similarly, Rao, Afshin, Singh, and Mozaffarian (2013) estimate the daily cost of a healthy diet to be approximately $1.50 US more than an unhealthy diet, equivalent to about $550 US per person per year. Other studies have obtained similar findings (Drewnowski, Darmon, & Briend, 2004; Jones, Conklin, Suhrcke, & Monsivais, 2014).

Other research, however, suggests a more nuanced relationship between dietary quality and cost. For instance, Carlson and Frazão (2012) find that healthier foods appearing more expensive when priced on a per-calorie basis may actually be less expensive if priced on the basis of edible weight or average portion size. In addition, Bernstein, Bloom, Rosner, Franz, and Willett (2010) find that people can achieve large improvements in the quality of their diets without increasing spending, for example by reducing spending on red and processed meat products, while purchasing more nuts, soy, and beans, or more whole grain products.

Even if healthy diets are not necessarily costlier in financial terms, some evidence suggests they may require a larger investment of time than less healthy alternatives (Blaylock, Smallwood, Kassel, Variyam, & Aldrich, 1999; Rand et al., 2012, pp. 39–40). For example, ready-to-consume processed and ultra-processed foods often contain more calories, higher amounts of salt, sugar, and fat, and lower amounts of important nutrients than unprocessed and minimally-processed food items (Moubarac et al., 2014; Standing Senate Committee on Social Affairs, Science and Technology, 2016, p. 6). In addition, some studies suggest that T2DM patients who try to adhere to healthy eating habits spend substantially more time engaged in meal planning and in purchasing and preparing food than others do (Chernyak et al., 2017; Russell, Dong-Churl Suh, & Safford, 2005). Still others find that regularly eating home-cooked meals (though not necessarily more time allocated to food preparation, *per se*) is correlated with increased dietary quality (Mancino & Gregory, 2012; Mills, Brown, Wrieden, White, & Adams, 2017; Wolfson & Bleich, 2015).

2.5.2 Costs of engaging in physical fitness

Engaging in regular physical activity is not a costless endeavor, typically requiring substantial investments of both money and time. For example, the Canadian Fitness and Lifestyle Research Institute (2013b) reports that Canadian adults spend an average of $1,462 per year on sport, the largest shares of this being allocated to equipment ($488), memberships and registration fees ($379), transportation ($254), and clothing ($197).

Perhaps the most significant cost associated with participation in physical activity, however, is time (Moreland, 2014), including not merely the time actually engaged in exercise or sport, but also, for instance, the duration required for travel, for changing into and out of appropriate attire, and for warm-up and cool-down exercises. From an economic perspective, time is of course considered a scarce resource with many possible and competing uses. Unlike time allocated to the supply of labour, leisure-time physical activity (LTPA) does not generally augment household income, and thus cannot finance consumption. And in contrast to the way in which economists typically conceptualize leisure, time invested in physical activity is not necessarily a direct source of utility and, depending on the individual's preferences, could in some cases be considered a source of disutility.

With this in mind, it is not surprising that people often cite insufficient time as the reason for remaining physically inactive (Canadian Fitness and Lifestyle Research Institute, 2013a); for instance, nearly one-third (30.7%) of Canadians cited lack of time as a reason for non-participation in sport in the 2010 General Social Survey (Canadian Heritage, 2013, Table 26). Canadians who work longer hours are also more likely to cite time constraints as reasons for non-participation than other respondents (p. 10). The fact that Canadians' leisure time has declined by approximately 7% over the last two decades may have also decreased the optimal level of LTPA for some individuals (Canadian Heritage, 2013, p. 76; Employment and Social Development Canada, 2015).

It is important to recognize that physical exertion can be viewed as the output of a production process that offers many opportunities for substitutability across inputs, most notably time. Although the time-intensity of some physical activities is irreducible (Gratton & Taylor, 2000, p. 56), in other cases it may be possible to achieve the same or greater benefits from physical activity by applying more effort over shorter periods of time, as exemplified, for example, by high intensity interval training techniques (Kamerow, 2015).

2.5.3 Costs associated with adherence to medical treatment

Although Canada's public health care system insulates Canadians from many of the financial costs associated with medical care, T2DM can also impose substantial costs on patients (Canadian Diabetes Association, 2011b).[6] One important cost element for diabetics which is not generally covered under the *Canada Health Act* is pharmaceuticals, such as OAGs and insulin. While public and private drug plans typically provide some coverage for T2DM patients, the costs patients themselves bear can vary across jurisdictions (Diabetes Québec & Canadian Diabetes Association, 2011).

Manitoba's Pharmacare Program requires households to pay an annual deductible towards the costs of their medications, but provides full coverage for all subsequent expenditures (Manitoba Health, Seniors and Active Living, 2017b). Many Canadians are enrolled in private insurance plans (e.g., through their employer) that may insulate them from the costs of pharmacotherapy for T2DM.

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6 Even if the direct costs of medical care are fully insured, as they are in Canada, individuals may still be required to contend with significant financial barriers as they seek to access care; some patients, for instance, may be unable to forgo the wages they earn from working rather than obtaining care, while others may be unable to afford the cost of transportation to and from medical appointments (Ngo-Metzger, Sorkin, Billimek, Greenfield, & Kaplan, 2012, p. 432).

3. ECONOMIC MODELS OF THE PRODUCTION OF AND DEMAND FOR HEALTH

Models of health production seek to explain why and how health contributes to well-being. Extensions to these models may also seek to explain how decisions individuals make regarding health affect and are affected by choices in other areas of their lives, such as the level of educational attainment they should seek or the age at which they should retire.

This section briefly reviews and critiques key economic models pertaining to patient decision-making in the context of health promotion and maintenance. One theme emerging from a review of this literature is that decisions that appear irrational from the standpoint of health professionals may be viewed as rational when considered from the constraints and opportunities available to the patient. Even non-compliance with medical advice can conceivably be viewed as the outcome of rational decision-making in some contexts. For example, advice may be ignored if following it would require outlays of money or time that are difficult or impossible for the patient to accommodate within the constraints imposed by their budget or schedule, or if adherence implies tradeoffs that the patient deems unpalatable. This insight applies equally to programs and policies developed to promote public health.

3.1 Health as human capital: the Grossman model

In Grossman's (1972) seminal model, people care about health because it increases the time available for work, because the experience of illness reduces utility, and because they may die if their health declines too much.

Individuals in the Grossman Model do not purchase health. Rather, they contribute to a stock of health capital by combining inputs purchased in the marketplace (i.e., medical care) with their own resources (i.e., time engaged in health-promoting activities). Health capital, in turn, is an input in the production of healthy days the individual can then allocate to activities that promote their well-being. However, an individual's stock of health capital depreciates in a predictable fashion with time, with the depreciation rate increasing as they age, reflecting the observation that health tends to deteriorate more rapidly over time.[7]

People have limited amounts of time and income. They cannot spend more time working, participating in health-promoting activities, producing household goods,

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7 Grossman (1972) justifies this as follows: "Despite the existence of a wide variety of possible time paths, it is extremely plausible to assume that [depreciation] is positively correlated with age after some point in the life cycle. This correlation can be inferred because, as an individual ages, his physical strength and memory capacity deteriorate. Surely, a rise in the rate of depreciation on his stock of health is merely one manifestation of the biological process of aging" (pg. 236). One important implication of an increasing depreciation rate is that the optimal stock of health capital will tend to decline with age, meaning, among other things, that individuals are assumed to choose how long they will live (Folland, 2013; Grossman, 1972, p. 225; Sloan & Hsieh, 2012, pp. 46–51).

or experiencing illness, than there are hours in the day, and discounted lifetime expenditures on medical care, other expenditures, and leisure must not exceed the value of their starting assets plus the discounted value of their lifetime earnings.

The individual's optimization problem involves choosing levels of health and other consumption goods to maximize utility over time, subject to the constraints just described. This is accomplished when the present value (PV) of the marginal cost of gross investment in health in any period equals the PV of marginal benefits (i.e., increased income and utility from more healthy days); and when the decision-maker can increase their health stock by the same amount by purchasing an additional dollar of medical care or spending an additional dollar on time (expressed in terms of foregone wages).

3.2 Health as the modification of a stochastic process: the Zweifel, Breyer, and Kifmann ("ZBK") model

Two characteristics of the Grossman Model present problems for examining optimal health-related decision making. First, although it was subsequently modified to introduce stochasticity (Bolin, 2013; Dardanoni & Wagstaff, 1990; Liljas, 1998; Picone, Uribe, & Wilson, 1998), the original Grossman Model was deterministic, implying that a forward-looking individual could be certain of the consequences of his or her choices. However, despite rapid advances in medical science it is not yet possible for a patient or physician to precisely forecast future health outcomes.

Second, it is unclear how the Grossman Model (or any variant thereof that conceptualizes health in terms of a stock of health capital), could be adapted to reflect the distinctive characteristics of specific chronic diseases, including T2DM. Disease appears effectively indistinguishable from the aging process, which takes the form of gradual (but accelerating) depreciation of an individual's health capital.

An alternative approach introduced by Zweifel et al. (2009, Chapter 3), with roots dating back at least as far as Arrow (1973) and Zeckhauser (1970, 1973), moves away from the conceptualization of health as a stock capital that accumulates or decumulates in a predictable fashion. Instead, the evolution of health is viewed in terms of movement through a series of well-defined states, transitions between which occur randomly. People can influence the likelihood of either maintaining (if healthy) or recovering (if ill) good health in the future by allocating their time and/or income to this endeavour, but no level of investment entirely rules out the possibility of future ill health (Zweifel et al., 2009, p. 96).

ZBK model

IF HEALTHY (*h*)		**IF SICK (*s*)**	
(1)	$\pi_{h,t+1} = \pi_{h,t+1}\left[\phi_{hs}\left(t^{I},...\right)\right];$ $\partial\pi_{h,t+1}/\partial t^{I} > 0, \pi_{h,t+1} > 0$	(2)	$\pi_{s,t+1} = \pi_{s,t+1}\left[\phi_{ss}\left(M,...\right)\right];$ $\partial\pi_{s,t+1}/\partial M < 0, \pi_{s,t+1} > 0$
(3)	$C_h = C_h\left(X, t^{C}\right)$ $\partial C_h/\partial X > 0, \partial C_h/\partial t_c > 0$	(4)	$C_s = C_s\left(X, t^{C}\right)$ $\partial C_s/\partial X > 0, \partial C_s/\partial t_c > 0$
(5)	$wt^{w} = p_x X$	(6)	$\overline{Y} = p_x X + p_m M$
(7)	$1 = t^{c} + t^{I} + t^{w}$	(8)	$1 = t^{c} + \mu M$
(9)	$EU = \sum_{t=0}^{T}\beta^{t}\left[\left(1-\pi_t\right)u_h\left(C_{h,t}, H_t\right) + \pi_t u_s\left(C_{s,t}, H_t\right)\right]$		

NOTE: π ≡ state occupation probability (likelihood of being in a specific state next period); ϕ ≡ state transition probability (likelihood of transitioning from one state this period, to another next period); C_h ≡ consumption while healthy; C_s ≡ consumption while sick; X ≡ consumer goods; M ≡ medical care; t^c ≡ time engaged in consumption; t^I ≡ time invested in health; t^w ≡ time engaged in work (i.e., labour supply); w ≡ wage rate; p_x ≡ price of market goods; p_m ≡ price of medical care; μ≡ time cost associated with receiving medical care; $\bar{Y}$ ≡ social security income; β ≡ subjective rate of time preference; H_t ≡ health status at time t, where $H_t \in [Healthy\ (h), Sick\ (s)]$.

Adapted from: Zweifel et al. (2009, p. 97)

If a person is well, Equation (1) indicates that they can reduce the likelihood of occupying a state of bad health in the next period by allocating their time to health-promoting activities such as leisure-time physical activity; however, once a person is sick, Equation (2) shows that they cannot regain good health on their own, but must instead rely on medical care. This discussion implies that the functional form of the production function depends upon the state of health in the immediately preceding period. Put another way, health is both an input and output of the production process. I should note that the probability of occupying a specific state at time *t* (denoted by π) is distinct from the probability of transitioning to said state at that moment (denoted by ϕ).

Equations (3) and (4) indicate that people must "process" consumer goods in the household before they can be enjoyed. In addition, Equations (5) and (6) are income constraints for the healthy and sick states, respectively, while Equations (7) and (8) are time constraints. As with the production functions, the constraints exhibit state-dependence. Healthy people earn income through work (the amount of which is determined by the prevailing wage rate, and how much labour they choose to supply), which they use to purchase consumer goods, whereas sick people are reliant on social security income, which they divide between consumer goods and medical care. Analogously, healthy people allocate time to engage in consumption, work, and/or health-promoting activities, while sick people use their time for consumption or receipt of medical care.

Equation (9) shows that the individual's expected utility is the weighted average of their well-being in the healthy and sick states, with the state probabilities serving as the weights. Intuitively, it reflects the payoff the individual expects to receive from investing in their health. This specification allows the utility function to be state-dependent in much the same way as the production function.

That the utility and production functions exhibit state-dependence, suggests something similar will be true of the optimality conditions. Indeed, if the marginal utility of consumption is increasing in health, the marginal rate of substitution between consumption and the probability of good health will be lower when well than when ill. That is, because a healthy person derives more marginal utility from consumption than a sick person, he or she is less inclined to invest in his or her health (Zweifel et al., 2009, pp. 92–93).[8]

To extend the analysis beyond two periods, Zweifel et al. (2009) suppose that an individual makes a one-time investment in the present that affects the mean length of time he or she can expect to live in good or bad health, respectively, depending on the individual's current state of health:

- *Currently healthy.* People who are healthy will want to remain so. For such individuals, health has the characteristics of an investment when dedicating an hour to its maintenance yields more than an hour in additional healthy time. However, it takes on the characteristics of a consumption good when, due to

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8 This is an important result, in that it reconciles rational choice theory with the common perception that patients seem to exhibit very little willingness to invest in health when they are well, while resorting to extreme measures to recover their health once affected by illness or injury (Zweifel, Breyer, & Kifmann, 2009, pp. 101–103). However, Zweifel et al. (2009) assert that the "instability" of health behaviour could also result from the state-dependent nature of the health production process.

diminishing returns, an hour invested in health results in less than an hour of healthy time.

- *Currently ill.* People who are sick want to recover from illness as quickly as possible. For such individuals, time allocated to improving health (i.e., lifestyle modification and/or receiving medical care) is never an investment, since time is not an input in their health production function.

Medical care and time invested in health-promoting activities in the ZBK model can be considered substitutes for a person entering the model in the healthy state, but complements for a person in the sick state (Zweifel et al., 2009, pp. 107–109). If a person is presently well, investing in health through one's own efforts reduces the probability of falling ill, and so reduces future demand for medical care. By contrast, if a person is presently ill, by enabling a speedier return to health, purchasing medical care enables him or her to more readily invest in their own health.

3.3 Extending the ZBK model: dynamic programming

Although Zweifel et al. (2009) extend their model to encompass multiple periods, the results of their analysis necessitate the imposition of fairly restrictive assumptions, namely that the longer-term tradeoff can be couched in terms of short-term consumption versus the expected duration of good health enjoyed before being afflicted with illness (i.e., as opposed to the likelihood of remaining healthy in the subsequent period); and that decision-makers effectively do not think beyond their current phase of good health (page 103).

If these simplifying assumptions are dispensed with, more sophisticated techniques are required to operationalize the model and solve the accompanying optimization problem. Since I did not identify any literature documenting the application of these techniques within the context of the ZBK model, this potentially represents a gap this thesis is well-positioned to fill.

Dynamic optimization problems like the one at the heart of the ZBK model can be solved in a variety of ways, including the method of Lagrange multipliers, the calculus of variations, the maximum principle, and dynamic programming (DP) (Conrad, 2010, pp. 26–30; Miranda & Fackler, 2004, pp. 388–389; Wickens, 2012, pp. 546–548). In this section I focus primarily on DP, as it is uniquely-suited to discrete-time optimization problems that incorporate stochasticity (Ferguson & Lim, 2003, p. 92).

The key to DP is Equation (10) below, also known as the Bellman Equation, which states that the maximal utility flow the decision-maker can expect to enjoy from time t onward, given that they currently occupy state s (i.e., also known as the value function), given their current circumstances as reflected by occupation of the state denoted by *s*, can be expressed as the largest possible sum of current net rewards (i.e., the utility derived from this period's choice, as represented by the first term in the brackets) and expected future rewards (i.e., the discounted value associated with all decisions from now until the end of the model horizon, as represented by the second term in the brackets). The decision-maker is assumed capable of determining and influencing their current and future rewards, respectively, by selecting a particular course of action (denoted by *x*) from among the set of all actions available to them (denoted by *X(s)*, where the notation implies a person's choices may be conditioned by their current circumstances):

(10) $$V_t(s) = \max_{x \in X(s)} \left\{ f(s,x) + \delta \sum_{s' \in S} P(s' \mid s,x) V_{t+1}(s') \right\}, s \in S, t = 1,2,\cdots$$

An essential insight emerging from the Bellman Equation is that one can solve T-period intertemporal optimization problems by conceptualizing them as sequential two-period problems (Adda & Cooper, 2003, p. 12).

In contrast to static optimization problems, the objective in DP is to select an *optimal policy*—a sequence of actions one should take from now until period T to maximize the value function, given that they currently occupy state *s*:

$$x_t^*(s) = \underset{x \in X(s)}{\arg\max} \left\{ f(s,x) + \delta \sum_{s' \in S} P(s' \mid s,x) V_{t+1}(s') \right\}, s \in S, t = 1, 2, \cdots \tag{11}$$

The key to identification of the optimal policy is the principle of optimality (Miranda & Fackler, 2004, p. 179), which states that any optimal policy should be characterized by time-consistency, which is to say that if the decision-maker were to stop part-way through the model and reconsider their plans, they would not make any changes (Ferguson & Lim, 2003, p. 83)—or, alternatively, that "you'll make the most of what you have started with if you always make the most of what you have left" (Nahin, 2007, p. 316).

If the decision-maker knew the maximal expected utility flow resulting from each action (i.e., the second term in brackets in Equation (10)), the problem would be trivial, since they could simply contrast the sum of current and future utility and select the action yielding the largest value. However, it is hardly intuitive that the decision-maker would know this, since it is influenced by what action is taken now. That is, the information needed to make a choice appears driven by that decision. Chapter 3 describes how this paradox is resolved.

Before proceeding, it is worthwhile showing how the ZBK model can be reframed using DP, which I do in Equation (12):

$$V_t(h) = \max_{x \in X(h)} \left\{ u_h\left(C_{h,t}, H_t\right) + \beta \begin{bmatrix} \phi_{hs}\left(t^I\right) \times V_{t+1}\left(h_{t+1}\right) \\ +\left(1-\phi_{hs}\left(t^I\right)\right) \times V_{t+1}\left(s_{t+1}\right) \end{bmatrix} \right\}$$

(12) $$V_t(s) = \max_{x \in X(s)} \left\{ u_s\left(C_{s,t}, H_t\right) + \beta \begin{bmatrix} \left(1-\phi_{ss}(M)\right) \times V_{t+1}\left(h_{t+1}\right) \\ +\phi_{ss}(M) \times V_{t+1}\left(s_{t+1}\right) \end{bmatrix} \right\}$$

$$H_t \in [h, s],\ t = 1, 2, \cdots$$

As shown, the ZBK utility function can be readily substituted in for the original generic reward function, while the summation operator has been replaced by the weighted sum of next period's value functions with the state transition probabilities from Equations (1) and (2) serving as the weights. Also noticeable in Equation (12) is the dependence of the value function on the patient's initial state. Not only may the structure of the utility function vary with a person's state of health, but so too will the state transition probabilities they face, as well as their capacity to influence future outcomes through participation in health-promoting activities (if well) or receipt of medical care (if ill). In this sense, Equation (12) preserves one of the key messages emerging from the ZBK model, namely that one's current circumstances can materially affect their future prospects for health and wealth—and, consequently, the choices they might make over their lives.

4. CONCLUSION

This section summarizes how the findings presented in this chapter can be integrated into a model that examines health-related decision-making from the perspective of an individual patient.

QUESTION #1: What are the defining clinical attributes of T2DM? How does T2DM influence an individual's well-being?

T2DM is a progressive chronic disease characterized by the body's inability to produce or to properly use insulin. While the condition itself is irreversible, lifestyle modification and adherence to therapy can help to avoid or delay its development and can assist in managing its progression. T2DM development and progression in individual patients can rarely be predicted with certainty and plays out over long periods of time. Moreover, because T2DM is not always symptomatic at early stages, patients often present with undetected complications.

T2DM and the health complications with which it is associated commonly manifest in reduced average life expectancy, diminished HRQoL, adverse effects on labour market participation and performance, and increased allocation of household resources to the preservation of health.

QUESTION #2: What factors contribute to the emergence and progression of T2DM? Which of these can the individual influence, and which lie beyond their control? What constraints does an individual face in trying to reduce their risk of T2DM and diabetic complications?

Factors influencing the likelihood of the emergence and progression of T2DM that people can control include presence of prediabetes, overweight/obesity, physical inactivity, sedentary lifestyles, high blood pressure and/or cholesterol levels, and smoking; factors typically outside their control include genetics (e.g., family history and ethnicity), age, history of gestational diabetes, and other medical conditions. One can reduce—but not usually eliminate—the risk of developing T2DM by investing time and/or money in health-promoting products, services, and activities, but both resources are finite and have competing uses.

QUESTION #3: What existing economic models and frameworks can be used as the basis for the optimization problem, and what are the strengths and weaknesses of each approach? How might these be adapted to achieve the objectives of this research, given what is known in relation to the questions outlined above?

The Grossman model and the ZBK model each contribute to our understanding of why people care about their health, how they maintain it, and why they may neglect it or even engage in activities injurious to health. I consider the following in evaluating the suitability of each model in relation to my research objectives:

- ❖ As the development and progression of T2DM plays out over long periods of time, a dynamic optimization model is preferred to a static model. Both the Grossman and ZBK models incorporate the passage of time, although they conceptualize this differently (i.e., as a continuous or discrete variable).

- ❖ The model should allow health status to evolve stochastically, since the T2DM development and progression is influenced by many factors beyond the individual's control. The ZBK model satisfies this criterion, but the textbook Grossman model does not (though variants do). Both assume people are always cognizant of their health status and the implications of their choices.

- ❖ It is intuitively appealing to conceptualize health dynamics as a series of transitions between well-defined states, as in the ZBK model, in part because this approach bears similarity to the Markov models commonly used in health economic evaluations. By contrast, it is unclear how one might conceptualize T2DM in terms of the accumulation and decumulation of health capital, which is a defining feature of the Grossman Model.

- As just implied, both the Grossman and ZBK models recognize that constraints on time and income limit people's ability to invest in their health.

- We can model the impact of T2DM on individual welfare in a variety of ways. Health status may directly enter the utility function, as in the ZBK model, or may facilitate production of a good that promotes well-being, as in the Grossman Model. Illness may also increase the likelihood of death or affect how patients allocate time and income in ways that detract from their welfare.

Although they share many features, I regard the ZBK model's conceptualization of the evolution of health status (i.e., probabilistic transitions between states) as better suited to achieving my research objectives than that of Grossman's model (i.e., deterministic accumulation and decumulation of health capital). However, the ZBK model requires several modifications to perform this function, including

- extending the model to an arbitrary number of periods, by building on the discussion in Section 3.3 above;

- characterizing the set of states that people at risk for T2DM could conceivably occupy, and of choices that can influence their likelihood of experiencing those states—which should include not merely states/choices that relate to health status, but also those pertaining to labour force participation;

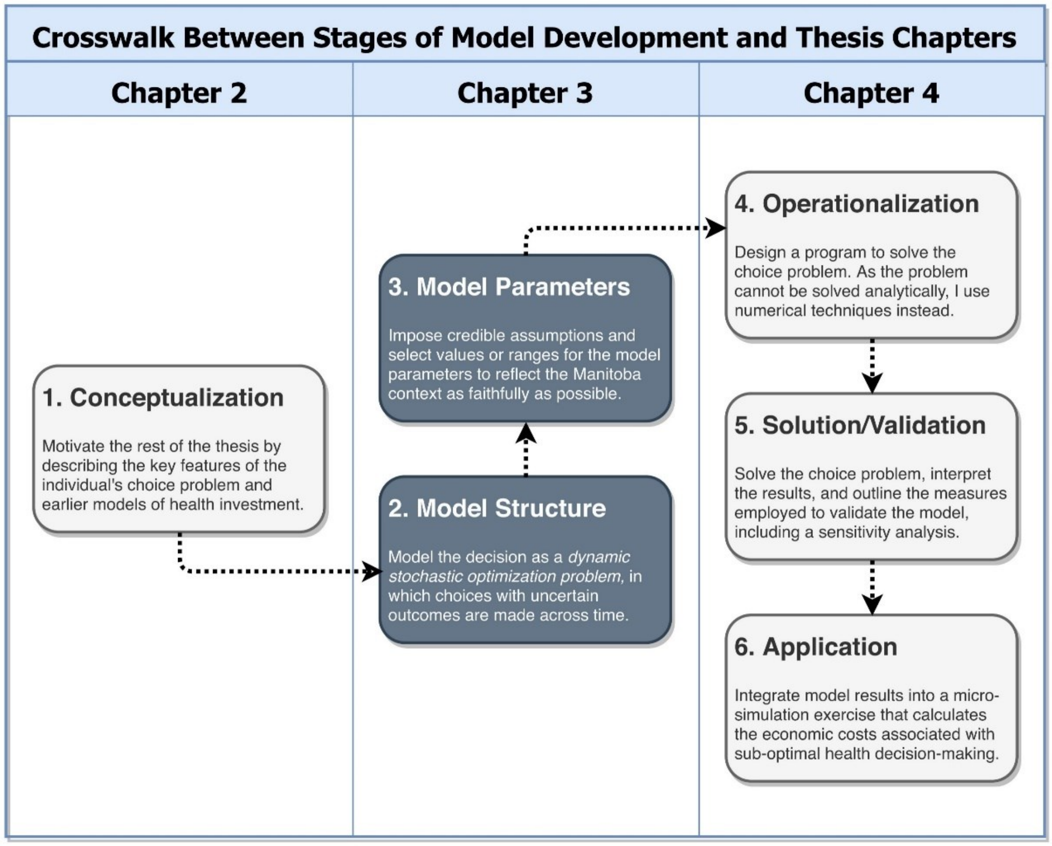
- and, surveying the academic literature and other available resources to select credible values or ranges of values for all key parameters.

It is to this task that Chapter 3 now turns.

Chapter 3: MODEL SPECIFICATION

1. INTRODUCTION

Building upon the insights generated through the literature review, Chapter 3 documents the construction of, and adoption of parameter values for, a model in which rational economic agents allocate scarce resources to maximize well-being, while incorporating lifestyle choices that may influence their risk of experiencing type 2 diabetes mellitus (T2DM) and its complications.



As shown in the figure above, there are two components to this activity:

❖ *Specify the model structure.* As noted in the previous chapter (and Section 3.3 in particular), this entails extending the simple two-state, two-period Zweifel, Breyer, and Kifmann (ZBK) model. A range of modifications are required to achieve this study's objectives, perhaps the most significant of which relates to the choice of solution methods; as I shall discuss, the model is too complicated to solve analytically, necessitating use of numerical techniques.

- *Impose credible assumptions and select values/ranges for model parameters.* The goal of this thesis is to study optimal health-related decision-making in Manitoba. Correspondingly, I select values for model parameters to mirror the Manitoba context as faithfully as possible. Where Manitoba-specific values are unavailable or of uncertain quality, or where parameters may vary across individuals, I substitute values from Canadian or international sources, or draw the parameter in question into the sensitivity analysis conducted in Chapter 4. The model also incorporates several assumptions intended either to promote realism, or to manage the computational resources required to set up and solve the decision problem. The thesis takes pains to detail the basis for the many parameters used in the model to ensure the simulations are credible and can support policy recommendations.

2. KEY CONCEPTS

2.1 Outline of the individual decision model

This section begins by offering a brief, non-technical overview of the decision model, with the narrative accompanied by a diagrammatic representation of the model presented in Figure 2.

Over the course of their lives, individuals with pre-defined characteristics (i.e., gender, ethnicity, and level of educational attainment) transition through a series of states that reflect the aging process and the evolution of health and employment status. Some transitions, such as aging, occur with certainty, while others occur randomly. Individual cannot eliminate the risk from their lives but can act in ways that increase the likelihood of desirable state transitions.

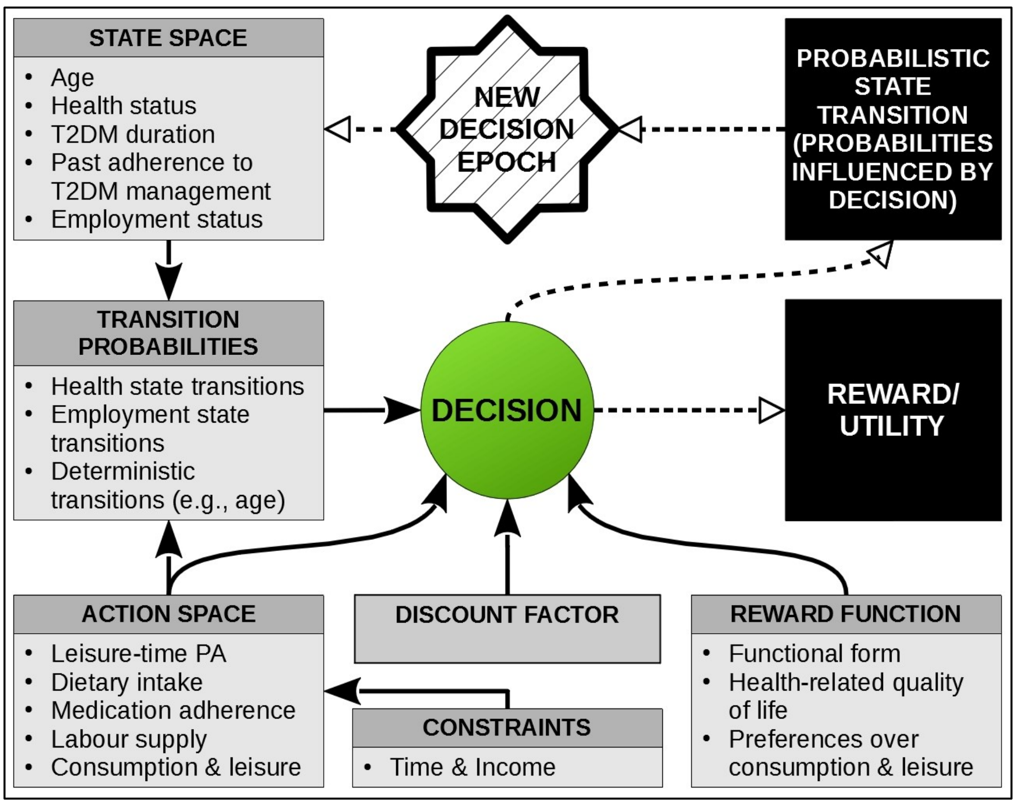


Figure 2: Diagrammatic representation of the structure of the decision model

The individual decision-maker makes a series of sequential choices about their health, including whether to adhere to regular participation in leisure-time physical activity (LTPA), to healthy eating habits, and/or to prescribed courses of pharmacotherapy. They must also determine how much time, if any, to dedicate to the generation of income in the labour market. For simplicity, time is conceptualized as discrete, with decisions being made annually. Moreover, the set of actions open to the individual is assumed to be finite, limiting the range of alternatives they must consider. The individual takes the following factors into account in considering the nature of the problem they face:

- ❖ Their present state (i.e., age, and health, T2DM duration and employment status).
- ❖ The nature of their preferences (e.g., the degree to which they regard certain health states as desirable or undesirable, their willingness to defer consumption into the future, etc.), as reflected in the functional form and parameters of the reward function, as well as the value of the discount factor.
- ❖ Constraints on time and income that further restrict what kinds of decisions they can make.
- ❖ Personal characteristics such as gender and ethnicity do not change over time.

Depending on the course of action selected, the individual immediately earns a reward (or within-period utility) corresponding to their current health-related quality of life and the level of consumption and leisure they now enjoy. Their choice, together with their current circumstances, also influence—but do not typically determine—which state they will experience next. The pervasiveness of risk means people must form expectations about the likelihood of certain events taking place in the future, but this is simplified by the fact that only a limited number of states can be accessed from any other. The constraints facing the decision-maker are closely related to the individual's personal characteristics and their current state. For example, their level of educational attainment affects how much income they have available to spend, while their health status may affect how much time is lost to illness.

The fundamental dilemma patients face is that although making healthy choices in the present increases the likelihood of occupying desirable states in the future, it also requires them to allocate time and income that could otherwise be used to engage in consumption or enjoy leisure. In coming to grips with this dilemma, the model assumes the agent will ultimately settle upon a comprehensive strategy that stipulates a course of action for any situation they may encounter. Furthermore, the nature of the solution will be such that the decision-maker will never be tempted to deviate from it, no matter what they subsequently experience in life.

2.2 General assumptions

I introduce the following assumptions to manage the complexity and ensure the model's tractability:

- *Individuals are rational and health literate.* Economic agents have the mental capacity and knowledge required to accurately evaluate how their decisions influence the probability of experiencing health state transitions. This is by no means an innocuous assumption, given a growing behavioural economics literature suggesting that, for example, assessments of the risks of events that may affect an individual's well-being often deviate significantly and in a predictable fashion from the actual probabilities (Moser, Patnick, & Beral, 2007; von Wartburg, 2011), that responses to receipt of health-related information frequently depend upon how the information is presented or framed (Grady, Entin, Entin, & Brunyé, 2011; Ledford, 2012), or that a person's willingness to delay gratification (e.g., to allocate time/income to diet and exercise now so as to enjoy better health later) may vary according to when the proposed tradeoff is expected to occur (i.e., hyperbolic discounting) (Frederick, Loewenstein, & O'Donoghue, 2002), resulting in dynamic inconsistency with respect to choices that can impact health (Cawley & Ruhm, 2011). I nonetheless assert that the assumption of full rationality and high health literacy on the part of decision-makers is appropriate for the purposes of this research, for the following reasons:

- Although new frameworks for modeling health-related decision-making that are informed by ongoing developments in behavioural economics have begun to emerge (as exemplified, for instance, by Ruhm's (2012) "dual decision" framework), the literature review found no evidence that any of these are sufficiently well-developed, widely accepted, and otherwise suitable for achieving the objectives of this study. It remains true, as Myerson (1999) once observed, that "reliably accurate and analytically tractable theories of the inconsistency and foolishness in human behavior simply have not yet been developed, and so our best analytical models are based on the rationality assumption for lack of any better foundation" (pg. 1069).

- Although it is arguable whether dynamic stochastic optimization problems such as the one outlined in this chapter constitute credible models of real-world decision-making, they can nonetheless fulfill a valuable role by motivating researchers and policymakers to consider how much could be gained by implementing programs, policies and other interventions that contribute to better-informed health decisions on the part of individuals.

This insight is central to the analysis undertaken in Section 5 in Chapter 4 below, which focuses on evaluating indirect costs to the Manitoba economy attributable to patterns of health-related decision-making that deviate from full rationality.

- *The model assumes single-unit households.* All households are assumed to be comprised of a single adult, to eliminate the influence of other household members on choices.

- *Consistency in the delivery of health care services.* All economic agents receive the same level and quality of care, which is furthermore delivered according to current Canadian standards.

- *The model focuses on agents aged 25-95, and all agents are assumed initially healthy.* This was done for the following reasons:

  - Many choices affecting the current or future health of children and adolescents are made on their behalf by parents or guardians.

  - It is beyond the scope of this research to study choices relating to investment in (non-health) human capital. Most individuals have completed their formal education by age 25.

  - The risk equations employed in Section 3.6.2 to derive the health transition probabilities for individuals with T2DM are based upon data from patients who were between the ages of 25 and 65 when diagnosed.

- *Limitations on saving and borrowing.* Because the decision model is "memoryless", it would only be possible to incorporate saving and borrowing by adding many more states, increasing the effort required to solve the model. To circumvent this, the model assumes the existence of an enforced savings mechanism that deposits a fixed proportion of employment income in a retirement fund, the contents of which are withdrawn beginning at age 65.

- *No private insurance coverage for pharmaceuticals.* The model assumes that Manitobans with T2DM take advantage of their provincial Pharmacare program, and that this is only source of financial support available to help Manitobans manage the cost of their medications.

- *Financial costs of treating T2DM experienced by the individual are limited to pharmacotherapy.* The model currently excludes other medical services such as dentists, psychologists, chiropodists/podiatrists and optometrists.

- *No comorbidities or concurrent health conditions.* The model effectively assumes a world in which there is only a single chronic disease, excepting microvascular and macrovascular complications of T2DM.

- *No Employment Insurance (EI).* EI extends benefits to Canadians who have lost their positions due to factors outside their control, and who are able and willing but experiencing challenges finding work (Employment and Social Development Canada, 2016b). Incorporating EI programming would require tracking the duration of unemployment, which would in turn require adding additional states. As such, I assume unemployed individuals rely on Employment and Income Assistance (EIA) while searching for new work.

- *Restrictions on ability to modify health-related behaviours post-diagnosis.* The model assumes individuals with T2DM can revisit their decision to adhere to LTPA, healthy eating habits and compliance with pharmacotherapy at most twice following diagnosis—immediately upon being diagnosed (i.e., between Years 0 and 1), and again between the 9th and 10th years of living with T2DM. The rationale for this approach is that although the progression of T2DM depends on an individual's entire history of health-related decisions, reflecting this in the structure of the decision model causes the number of health states to grow exponentially.

2.3 Defining lifestyle

Given that this research is fundamentally concerned with the determinants and outcomes of health-related decision-making, it is important to outline how these decisions are defined and operationalized in the model. The model incorporates three specific categories of health choices known to influence the likelihood of T2DM emergence and progression, namely participation in leisure-time physical activity; dietary intake; and, adherence to pharmacotherapy.

2.3.1 Physical activity

Physical activity can be defined as bodily movement produced by skeletal muscles that expends energy and increases heart rate and breathing (Canadian Society for Exercise Physiology, 2013, p. 2; World Health Organization, 2015). It can be classified according to where it is undertaken (e.g., in the workplace, or during a person's leisure time), the level of intensity it entails, and the types of activities it involves (e.g., aerobic exercise, resistance exercise, flexibility exercise, etc.). As noted in Chapter 2 (Section 2.1.2), there is strong evidence that participation in LTPA facilitates the prevention and treatment of T2DM.

This research focuses primarily on the duration over which individuals engage in moderate-to-vigorous-intensity aerobic physical activity during their leisure time, excluding other forms of physical activity from consideration. Additional simplifying assumptions include the following:

- *No work-related physical activity.* While some evidence suggests work-related physical activity contributes significantly to reducing the risk of T2DM (Sarma, Devlin, et al., 2014; Sarma, Zaric, Campbell, & Gilliland, 2014), because people generally have limited discretion over how much and what types of physical activity they may encounter at work, it is not incorporated into the decision model.

- *No financial costs associated with LTPA.* Although some recent studies Canadians dedicate a significant proportion of household income to involvement in physical activity and sport (Business Development Bank of Canada, 2013; Canadian Fitness and Lifestyle Research Institute, 2013b), participation in many forms of physical activity requires minimal investment of household resources.

- *No negative impact of sedentary lifestyles.* Chapter 2 pointed out that many researchers now recognize physical inactivity and sedentary lifestyles as distinct risk factors for a range of chronic diseases (Canadian Society for Exercise Physiology, 2013). In its current formulation, however, the decision model focuses primarily on the former.

2.3.2 Dietary intake

There is also strong evidence that diet can influence one's risk for developing T2DM as well as its progression, a summary of which is presented in Section 2.3.1 in Chapter 2). However, since current Canadian and US clinical guidelines for treatment of patients with T2DM do not unambiguously support any specific nutritional intervention or prescription (American Diabetes Association, 2017a; Canadian Diabetes Association Clinical Practice Guidelines Expert Committee, 2013c), the model defines adherence to healthy eating habits with reference to the level and quality of dietary intake.

- *Caloric intake relative to energy needs.* The difference between caloric intake and expenditure is important because it determines an individual's energy balance—which, in turn, affects their weight. As noted in Chapter 2, there is strong evidence that the risk of T2DM is significantly increased in individuals who are overweight or obese.

- *Dietary quality.* The model assesses dietary quality with reference to scores on the Alternative Healthy Eating Index 2010 (AHEI-2010), a dietary index based specifically on foods and nutrients determined to be predictive of chronic disease risk. Previous studies do indeed suggest higher AHEI scores to be strongly associated with lower risk of several chronic diseases, including

T2DM (Cespedes et al., 2016; Chiuve et al., 2012; de Koning et al., 2011; Fung et al., 2005; S. Jacobs et al., 2015; Schwingshackl & Hoffmann, 2015). Details regarding the AHEI-2010 are presented in Appendix B.

2.3.3 Medication adherence

Pharmacotherapy is often an essential pillar of the treatment of T2DM, facilitating management of blood glucose and other risk factors for diabetic complications, as well as comorbidities. I define pharmacotherapeutic adherence with reference to the proportion of each year for which a patient has a supply of all prescribed medications, which is known as the medication possession ratio in empirical studies (Fairman, 2000, p. 502), and which can often be calculated using objective measures (e.g., claims data).

The model imposes the following assumptions in relation to medication adherence:

- *Pharmacotherapy initiated upon diagnosis of T2DM.* While some forms of pharmacotherapy may also supplement lifestyle modification as part of efforts to prevent or delay the onset of T2DM among individuals living with prediabetes, I assume patients with prediabetes are treated primarily through the latter.

- *Patients adhere with all medications purchased.* Implicitly, the model assumes that non-adherence stems from challenges in maintaining an ongoing supply of all prescribed medications, rather than their inability or unwillingness to use such medications as directed by their physician. It also implies patients consume their entire supply of medication.

- *Uniform adherence across medications.* Patients are equally adherent or non-adherent to all prescribed medication and medical supplies.

- *Non-adherence driven entirely by cost.* Although compliance with pharmacotherapy is often driven by other factors (see Section 2.5.3 in Chapter 2), I assume out-of-pocket expenditures are the only cost patients consider when deciding whether to adhere with prescribed medications.

3. SPECIFICATION OF MODEL STRUCTURE AND PARAMETER VALUES

The optimization problem described in Section 2.1 is studied using a finite-horizon, discrete time, discrete action/state Markov decision process model:

- *Finite-horizon.* The collection of decision epochs (i.e., the points in time at which choices can be made) is finite. Put another way, the phenomenon being studied plays out over a well-defined interval.

- *Discrete time.* The collection of decision epochs is conceptualized as a discrete set, rather than as a continuum.

- *Discrete action/state.* Although health evolves continuously, the model assumes that the agent occupies finite states denominated in years.

- *Markov decision process.* The Markov qualifier indicates that the set of probabilities governing the generation of future random variables is determined only by the model's current state and the action taken by the decision-maker. Markov decision processes are often described as "memoryless" in that choices taken and events occurring prior to the present are salient to current decisions only to the degree that they are reflected in the state the individual now occupies. This occurs whenever earlier choices affect the odds of navigating to a state or states which, in turn, significantly affect the likelihood of subsequent transitions. In some of these instances, the model also explicitly records what the person did at certain times.

Table 1 describes and itemizes the parameters driving the decision model. It also lists the sources of data used as the basis for selection of parameter values or ranges and identifies the sections in this document where additional details may be found. Some parameter values are modeled, which means I derive them from other parameters that do not enter the model themselves:

Table 1: Overview of model inputs			
Input type	**Input**	**Data sources**	**Section/page**
Decision epochs	Number of epochs	Assumed	Section 3.1 (pg. 87)
State space	Inputs pertain to the structure of the model itself rather than to the value of individual parameters and include the ages and number/type of health and employment statuses incorporated into the model. The model's design was selected by the author, although it was in many cases influenced by data availability.		Section 3.2 (pg. 88)
Action space	Inputs again relate to the structure of the model rather than to the value of individual parameters. These include the types of decisions people are permitted to make (i.e., allocation of time and/or income to labour market participation, health-related activities, and enjoyment of consumption and leisure), as well as the range of options associated with each. The model's design was selected by the author, although it was in many cases influenced by data availability.		Section 3.3 (pg. 96)
Reward function	Functional form	Academic literature	Section 3.4.1 (pg. 102)
	Elasticity of substitution	Assumed, but will be varied in sensitivity analyses.	Section 3.4.2 (pg. 106)
	Preferences over consumption and leisure	Assumed, but will be varied in sensitivity analyses.	Section 3.4.3 (pg. 108)
	Preferences over health states	*Healthy and prediabetic states:* Assumed	Section 3.4.4 (pg. 109)
		T2DM "states": **Modeled—**Preferences over health status are assumed to be closely tied to microvascular and macrovascular complications experienced over time. The values used in the model are derived from simulations carried out using the UKPDS-OM2, which are in turn driven by risk factor levels derived from the literature, as well as parameters furnished by Alva, Gray, Mihaylova, and Clarke (2014) and Lung, Hayes, Hayen, Farmer, and Clarke (2011).	
		Other states (i.e., dead): Assumed	
Constraints	Labour force income	Analysis of PUMF for the 2011 National Household Survey (NHS) (Statistics Canada, 2014), extrapolated to 2018 by applying the Consumer Price Index (Statistics Canada, 2018c)	Section 3.5.1 (pg. 114)

Table 1: Overview of model inputs			
Input type	**Input**	**Data sources**	**Section/page**
	Employment and Income Assistance (EIA)	Provincial government websites/ publications (Province of Manitoba Department of Families, 2017a)	
	Retirement income, including accumulated savings	*CPP, OAS & GIS:* Federal government websites/publications	
		Accumulated personal savings: Assumed. The number of periods is based on life expectancy (Statistics Canada, 2018a)	
	Tax structure, and CPP/EI contributions	Federal and provincial government websites/publications and other publicly available documentation	
	Age-related productivity decline	Assumed, but will be varied in sensitivity analyses.	
	Household savings	Assumed	
	Impact of T2DM on productivity and employment income	*Workplace absenteeism:* **Modeled—**UKPDS-OM2, using risk factor levels derived from the literature and average excess absenteeism figures from Sørensen and Ploug (2013).	Section 3.5.3 (pp. 139, 149)
		Distribution of the burden of absenteeism between workers and employers: Assumed, based on figures published by the Conference Board of Canada (2016).	Section 3.5.3 (pp. 147, 149)
		Workplace presenteeism: **Modeled—** Author-derived figures obtained using parameters furnished by Lavigne, Phelps, Mushlin, and Lednar (2003).	Section 3.5.3 (pp. 141, 149)
		Distribution of the burden of presenteeism between workers and employers: Assumed.	Section 3.5.3 (pp. 147, 149)
	Medication expenditures	Pharmacist consultation; provincial government websites/publications (i.e., relating to the Pharmacare Program); provincial formularies; other available literature and documentation.	Section 3.5.1 (pg. 119) and Appendix C
	Food expenditures	*Dietary composition:*	Section 3.5.1 (pg. 119) and Appendix B

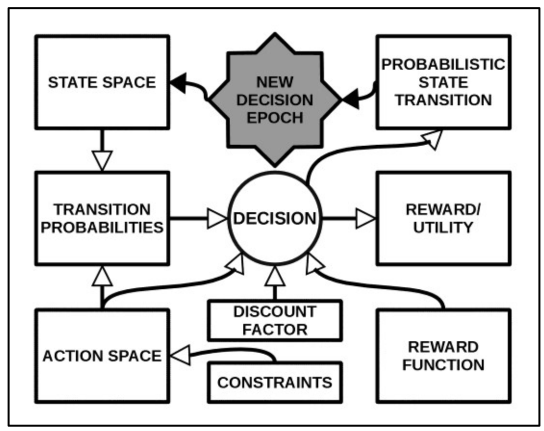
Table 1: Overview of model inputs			
Input type	**Input**	**Data sources**	**Section/page**
		• **Healthy diet**—Publicly available documentation (Winnipeg Regional Health Authority, 2010). • **Unhealthy diet**—Primary data collection conducted by author. *Dietary expenditures:* Prices derived using data collected from the website of a local supermarket chain (Loblaw's Inc., 2019). *Dietary quality:* Nutrient content of food evaluated using the Canadian Nutrient File (CNF) (Health Canada, 2016a). Dietary healthfulness assessed using the 2010 Alternative Healthy Eating Index (AHEI-2010) (Chiuve et al., 2012).	
	Expenditures associated with LTPA	Assumed	Section 3.5.1 (pg. 119)
	Consumption	Consumption is conceptualized as any income remaining after accounting for other household expenditures.	Section 3.5.1 (pg. 114)
	Time allocated to labour market activities	**Modeled—**Individuals have some discretion over the time they dedicate to earning income in the labour market, if employed). For unemployed individuals younger than 65, search hours are based on a figure published by the Organisation for Economic Co-operation and Development (2015).	Section 3.5.2 (pg. 135)
	Time allocated to LTPA	Individuals have some discretion over the extent of their participation in LTPA.	Section 3.5.2 (pg. 136)
	Time allocated to food preparation	Individuals have some discretion over the time invested in meal preparation. Assumed, based on a review of academic literature, especially Statistics Canada (2017a).	Section 3.5.2 (pg. 136)
	Time lost to illness	**Modeled—**Sick days consist of non-remunerated workplace absences, lost productive time attributable to illness experienced outside work hours. These are	Section 3.5.2 (pg. 131) and 3.5.3 (pg. 137)

Table 1: Overview of model inputs			
Input type	**Input**	**Data sources**	**Section/page**
		derived on an individual-specific basis using the same parameters employed to predict workplace absenteeism and presenteeism.	
	Time allocated to leisure	Leisure is conceptualized as any time remaining after accounting for other household expenditures.	Section 3.5.2 (pg. 137)
	Time allocated to other activities	*Time allocated to sleep:* Assumed *Time allocated to administering medication:* Assumed	Section 3.5.2 (pp. 131, 136)
Transition probabilities (movement between states)	Probability of health status transitions	*Healthy/prediabetic to T2DM:* **Modeled—** Predictions generated using the Diabetes Population Risk Tool (DPoRT) 2.0 risk equations (Rosella et al., 2014) and estimated energy requirements derived using equations published by the Institute of Medicine (Otten, Hellwig, & Meyers, 2006, p. 84)	Section 3.6.1 (pg. 154)
		Between T2DM "states": **Modeled—** Simulation results obtained using the UKPDS-OM2 (Hayes, Leal, Gray, Holman, & Clarke, 2013a), based upon risk factor levels derived from the literature	Section 3.6.2 (pg. 154)
		Mortality from healthy and prediabetic states: Life tables for Manitoba (Statistics Canada, 2018a)	Section 3.6.3 (pg. 173)
		Mortality from T2DM: **Modeled—**UKPDS-OM2, based upon using risk factor levels derived from the literature	Section 3.6.2 (pg. 154)
	Probability of employment status transitions	Analysis of PUMF for the 2011 Survey of Labour and Income Dynamics (SLID) (Statistics Canada, 2014)	Section 3.6.4 (pg. 173)
	Impact of T2DM on employment status transitions	Academic literature	Section 3.6.4 (pg. 180)
Discount factor	Rate of time preference/ discount factor	Assumed, but will be varied in sensitivity analyses.	Section 3.7 (p. 181)

The model consists of the following components: the decision epochs (Section 3.1); the state space (Section 3.2); the action space (Section 3.3); the reward function (Section 3.4); the constraints (Section 3.5); the transition probabilities (Section 3.6); and the discount factor (Section 3.7). Each of these is discussed in greater detail below. Additionally, Section 4 describes how these components are brought together to formulate and solve the optimization problem.

3.1 Decision epochs

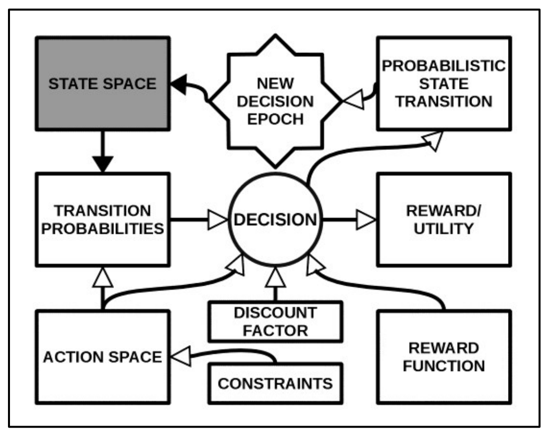
Decision epochs refer to moments in time where choices are made; decision epochs are assumed to correspond with the beginning of each period, implying they occur at regular intervals (Puterman, 2005, p. 18).



Beginning in the first period of the model, the decision-maker observes the state they currently occupy, selects a course of action, and earns a reward (or enjoys within period-utility), the magnitude of which depends both upon the agent's state and they choice they made. Similarly, although the state the individual will occupy during the next decision epoch cannot be known with certainty, his or her current state and the action taken may influence its distribution (Miranda & Fackler, 2004, p. 178).

The model incorporates 70 annual decision epochs or years representing ages 25 to 95. Decisions are not taken in the last decision epoch, since it is assumed individuals surviving to the 69th decision epoch (age 94) expire the instant before their next birthday. The model does not incorporate a final reward (in some models the decision-maker may earn a final reward—also known as a salvage value or scrap value—depending upon the state they occupy at that time).

3.2 State space



The state space refers to the collection of states in which an individual may find themselves during any decision epoch. In this thesis, the state space is assumed to be finite, meaning the number of states the decision-maker can occupy is limited in number. Moreover, a person may transition between states at the end of every period, but not in-between.

The state the individual occupies is important for the following reasons:

- ❖ It influences what actions can be taken in each decision epoch. For example, I assume that adhering to pharmacotherapy is a permissible option only for those who already have T2DM (see Section 2.3.3).

- ❖ When combined with their choices in any decision epoch and their preferences over consumption, leisure, and health states (as reflected in the structure and parameters of the reward function described in Section 3.4), it determines how much within-period utility they will experience.

- ❖ When combined with their choices in any decision epoch, it may affect the distribution of state transition probabilities, thereby influencing where they will end up in the subsequent epoch.

The state space for the decision model consists of 228,357 distinct states, each of which reflects a unique combination of age, employment status, health status, and, where applicable, T2DM duration and prior history of T2DM management (calculation of the size of the state space is undertaken in Table 2 below).

3.2.1 Age

The model examines decision-making by adults between the ages of 25 and 94. It is effectively assumed that 94-year-old individuals expire the instant before reaching their next birthday, and no choices are made thereafter. Given that only about 6.6% of men and 15.2% of women in Manitoba live until the age of 95, this is regarded as a reasonable simplification (Statistics Canada, 2017d).

3.2.2 Employment status

Individuals in the model are classified as either employed or unemployed. Individuals in the former category may opt to work full-time (i.e., 2,000 hours per year, if healthy), or part-time (i.e., 1,000 hours per year, if healthy) and, if aged 65 or older, may choose to retire, immediately earning retirement income, while transitioning to unemployment in the subsequent year with a probability of one.

Individuals who are unemployed and younger than age 65 are eligible to receive financial support through the Province of Manitoba's Employment and Income Assistance (EIA) Program but must search for work for as long as they do so. The model implicitly assumes that individuals younger than age 65 cannot exit the labour force. Upon reaching their 65^{th} birthday, individuals who are unemployed or who subsequently transition to unemployment need no longer allocate time to search, and may begin accessing several sources of retirement income, including the Canada Pension Plan (CPP), Old Age Security (OAS), the Guaranteed Income Supplement (GIS), and accumulated personal savings. People who have retired are categorized as unemployed and cannot re-enter the labour force.

3.2.3 Health status and T2DM duration and management

As the model processes decision-makers through their simulated lifecycles, they start healthy or prediabetic, but some will subsequently develop T2DM. Everyone will die in the model, but at different ages, with 94 being the maximum.

Because microvascular and macrovascular complications among diabetics often result in long-term or permanent impacts on an individual's health (including the risk of future complications), functioning, and quality of life, it is essential to account for these in the model. To accomplish this without creating additional states for every type of complication, the model accounts for these implicitly through HRQoL scores, mortality risks, and workplace absenteeism.

These derive from the results of simulations carried out using the UKPDS-OM2. Briefly, the simulations track the progression of T2DM within large cohort of simulated patients and generates results that reflect expected outcomes within the sample, as discussed in Section 3.6.2 below

T2DM duration

Since it is assumed economic agents cannot develop T2DM prior to the age of 27 and that all individuals expire prior to their 95th birthday, T2DM duration ranges between 0 and 67 years. Every time a diabetic survives from one year to the next, duration increments by one.

T2DM management

The model also keeps track of how patients are managing and have previously managed their condition.

Immediately following diagnosis, an individual can choose from among eight distinct approaches to T2DM management, since individuals can independently choose to adhere to healthy eating, LTPA, and/or pharmacotherapy, and since each choice is dichotomous (see Section 3.3.2 below). After living with T2DM for a full year, the model records the decision the individual made through appropriate state assignment, enabling the consequences associated with their choice to be carried forward into future years.

In the ninth year living with T2DM, the individual can modify their strategy for managing their condition. Beginning in Year 10, the model records both their most recent choice as well as the one they made immediately upon diagnosis. This implies that there are effectively 64 (i.e., 8^2) distinct sub-collections of diabetic health states an individual may occupy beginning in their tenth year of illness.

3.2.4 Summary of the state space

An overview of the state space is presented in Table 2 below:

Table 2: Overview of the state space incorporated into the decision model

Initial health status	Stage of T2DM Progression[1]	Possible ages	Possible T2DM durations	Possible T2DM management strategies: Per. 1	Possible T2DM management strategies: Per. 2	Possible employment statuses	Total number of states
Healthy/ prediabetic	N/A	70	N/A	N/A	N/A	2	**140**
T2DM						**Sub-total T2DM**	**228,216**
	Year of diagnosis	68	1 (i.e., Year 0)	N/A	N/A	2	136
	First decade	58	9	8	N/A	2	**Ages 36+:** 8,352
		9	Varies from 1-9 (depends on age)	8	N/A	2	**Ages 27-35:** $\sum_{N=1}^{9} 8 \times 2 \times a = 720$ [1]
	Established T2DM	58	Varies from 1-58 (depends on age)	8	8	2	$\sum_{N=1}^{58} 64 \times 2 \times a = 219{,}008$ [1]
Dead	N/A	N/A	N/A	N/A	N/A	N/A	**1**
						Total	**228,357**

[1] These sub-totals are calculated through the application of arithmetic series. In the first instance, the assumption that individuals are initially healthy/prediabetic implies limits on the number of years younger adults can already have lived with T2DM. In the second case, by contrast, this is attributable to the imposition of a maximum age restriction (i.e., age 95), which implies limits on the number of years a recently diagnosed individual can expect to live with the condition.

For individuals who are initially healthy or prediabetic, there are a total of 140 possible states, since healthy individuals may be any age and can be either employed or unemployed at any given time (i.e., 70 possible ages x 2 possible employment statuses), and since T2DM duration and management (neither of which are meaningful in this context) are not tracked.

In addition, there is a total of 228,216 states for individuals with diagnosed T2DM. This includes the following:

- 136 states in the year immediately following diagnosis (i.e., 1 year x 68 possible ages x 2 possible employment statuses), since T2DM duration is by definition 0 years, and since state assignment with respect to T2DM management commences only at the year's end.

- 9,072 states for the nine subsequent years:

  - *For individuals aged 27-35:* 8 possible configurations of health-related behaviours (see Table 3 below) x 2 possible employment statuses x ($\sum_{N=1}^{9} a = 45$) possible combinations of age and T2DM states, where *a* represents each possible age. The introduction of the arithmetic series in the final term reflects the fact that because individuals are initially assumed healthy, certain such combinations (e.g., a 27-year-old who has had T2DM for 10 years) cannot occur (720 states total).

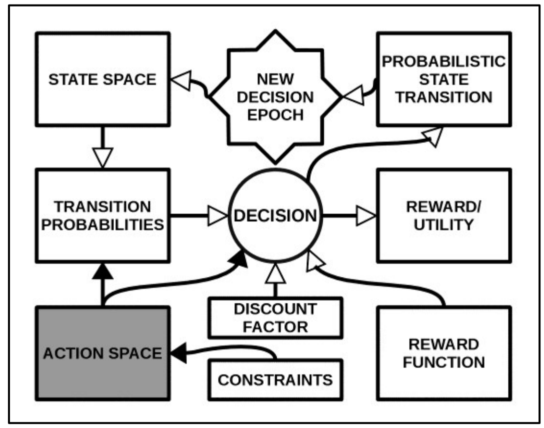
Table 3: Possible configurations of health-related behaviour		
LTPA	**Healthy eating habits**	**Pharmacotherapy**
Adhere	Adhere	Adhere
Adhere	Adhere	Don't adhere
Adhere	Don't adhere	Adhere
Adhere	Don't adhere	Don't adhere
Don't adhere	Adhere	Adhere
Don't adhere	Adhere	Don't adhere
Don't adhere	Don't adhere	Adhere
Don't adhere	Don't adhere	Don't adhere

- *For individuals aged 36+:* 9 years x 58 possible ages x 8 possible configurations of health-related behaviours x 2 possible employment statuses (8,352 states total).

- 219,008 states for years following the first decade (i.e., 64 possible configurations of health-related behaviours x 2 possible employment statuses x $\sum_{N=1}^{58} a$ states, where *a* represents each possible age). The arithmetic series in the final term again results from the assumption that individuals are healthy upon entering the model, which implies limits on the length of time they can be expected to have lived with T2DM.

The final state is an absorbing state occupied by all individuals who experience mortality, from the period in which death occurs until the end of the model horizon (strictly speaking, decision-makers cannot "exit" the model and must be accounted for somewhere).

3.3 Action space



The action space enumerates all choices an individual may make during each decision epoch (Miranda & Fackler, 2004, p. 178). Like the state space, the action space is assumed to be finite, meaning only a limited number of choices are available at any time.

Characterization of the action space involves enumerating the options the decision-maker might encounter and describing the conditions under which they are open to him or her. As presently structured, the model permits individuals to make choices regarding the nature and extent of their involvement in the labour market; their participation in activities that promote or detract from health; and their enjoyment of consumption and leisure.

Constraints on available time and income further restrict the decision-makers options (see Section 3.5 below), as may their current circumstances. For instance, the model assumes that individuals may not choose to retire from the labour force prior to the age of 65, and that individuals who are healthy or prediabetic do not have the option of adhering to pharmacotherapy. Moreover, decisions are often interdependent in the sense that some choices may preclude others. For example, electing to work part-time hours could in principle make it difficult or impossible for an individual to adhere to prescribed courses of pharmacotherapy.[9]

3.3.1 Labour market activities

During each decision epoch, individuals decide whether to work full-time or part-time, or, if age 65 or older and presently employed, to retire from the labour force. Consistent with the current design of the EIA program in Manitoba, it is assumed that individuals who are unemployed and younger than 65 are required to dedicate time to searching for work. It is further assumed that Manitobans who are unemployed when they reach the standard age of retirement automatically transition out of the labour force; that individuals cannot work and earn retirement income concurrently; and, that the retirement decision is irrevocable.

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[9] In fact, given the model's current formulation this does not occur, for two reasons. First, while T2DM can be an extremely costly illness, the Manitoba Pharmacare Program insulates individuals from a large proportion of the costs of pharmacotherapy. Second, the model does not account for household necessities other than food, such that there is always enough residual income to pay one's Pharmacare deductible. That said, it would be straightforward to simulate a situation like the one described in the text. One approach might involve extending the model to include the cost of shelter, which, like food, we could categorize as a necessity with a priority claim on any income net of taxes.

3.3.2 Health-related decisions

Health-related choices in the model relate to dietary quality, participation in LTPA, and adherence to pharmacotherapy. While the modelling framework does not strictly require it, for the purposes of this research each choice is dichotomous. A brief description of the health-related choices available to decision-makers is presented below, building upon the discussion in Section 2.3:

- *Participation in LTPA.* This involves engaging in regular moderate-to-vigorous-intensity aerobic physical activity. Non-adherence, by contrast, is assumed to consist of little or no weekly moderate-to-vigorous-intensity aerobic physical activity and no time commitment. Adherence to LTPA does not require any financial outlay.

- *Adherence to healthy eating habits.* This involves consuming a high-quality diet (as defined with reference to the AHEI-2010) that includes a level of energy intake needed to sustain a healthy body weight. Conversely, non-adherence involves consumption of a low-quality diet characterized by excessive caloric consumption. Individuals must commit both income and time to purchase, process, and ultimately consume food and beverages, although this investment may vary according to the diet chosen.

- *Adherence to pharmacotherapy.* This involves maintaining and self-administering all prescribed medications in such a way as to avoid any lapses in treatment. Non-adherence, by contrast, describes a situation in which patients never maintain a supply of any prescribed medication. It is assumed that adhering with pharmacotherapy may involve financial costs but relatively little investment of time. It is further assumed that pharmacotherapy is reserved for patients with T2DM.

As noted above, a person's current state may affect what types of health choices he or she can make. The most significant of these state-based restrictions relates to the frequency with which people can modify aspects of their lifestyle that influence disease progression. In particular, the model assumes individuals select a strategy for managing their condition immediately upon receiving their diagnosis and again nine years later but may not deviate from the approach they chose at any other time.

3.3.3 Enjoyment of consumption and leisure

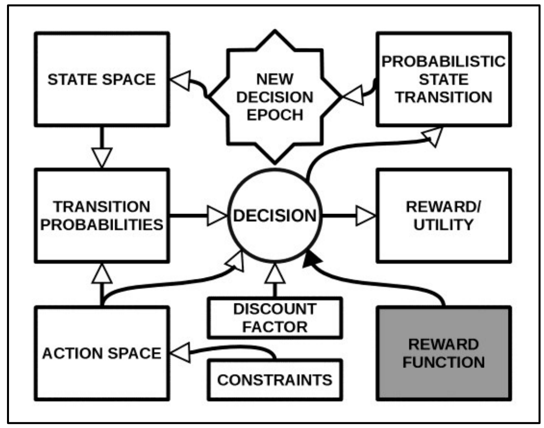
Income and time remaining after other demands on the household's resources have been met are, respectively, available for consumption and leisure, which constitute the primary sources of well-being for the decision-maker and figure prominently in the reward function. These categories of action are implicit, in the sense that the constraints incorporated into the model (discussed in Section 3.5 below) dictate how much of each the individual may enjoy once when other choices have been made.

While it simplifies the exposition to describe choices about dedication of household resources to consumption and leisure as though they were made sequentially, within a given decision epoch these choices are, in fact, made concurrently. It should also be recognized that the level of enjoyment the individual derives from each unit of consumption and leisure is mediated by their HRQoL—a point to which I return in Section 3.4.

3.3.4 Summary of the action space

Individuals have in principle 24 different options available to them during every decision epoch, including whether to adhere to LTPA (two choices), healthy eating habits (two choices) and use of prescribed pharmaceuticals (two choices), as well as whether to work full-time or part-time, or to retire. However, the individual's current state and constraints on their time and income may limit the types of choices they can actually make during any given decision epoch.

3.4 Reward function



The reward function indicates the reward—or within-period utility—that the decision-maker receives upon choosing a course of action in the current decision epoch. The design of the model is such that the reward the individual receives depends only on this action and on her current state.

The individual's actions are assumed to affect well-being by determining how much consumption and leisure they enjoy in the present. However, well-being is also mediated by an individual's health-related quality of life, which is indirectly linked to their choices in that the latter can influence the likelihood of desirable and undesirable health state transitions (see Section 3.6 below). Characterization of the reward function includes specification of its functional form, as well as selection of appropriate values for key parameters, including elasticity of substitution, and preferences over consumption, leisure, and health states.

3.4.1 Functional form

Since we do not generally know how health enters the structure of the utility function, health economists frequently use health state-dependent formulations in which $u(health_j, \gamma_j)$ is denoted $u_j(\gamma_j)$ (where γ_j denotes income, while subscript j denotes state), reflecting the possibility that functional form could vary across health states (Viscusi, 2014; Viscusi & Evans, 1990). Several prior studies have achieved this by incorporating health status as a multiplicative factor (Bleichrodt & Quiggin, 1999; Finkelstein, Luttmer, & Notowidigdo, 2008; Galama, Kapteyn, Fonseca, & Michaud, 2013; Hall & Jones, 2007; Kotlikoff, 1986; Levy & Nir, 2012; Viscusi & Evans, 1990), and the same approach will be applied here:

(13) $u_t\left(f\left(h_t\right), c_t, \ell \qquad \ell\right.$

One implication of state dependence is that the marginal utility of consumption can increase or decrease with health (Viscusi & Evans, 1990). Since many goods and services, such as travel can be viewed as complements for good health (i.e., we derive greater enjoyment from them when feeling well), one might expect the marginal utility derived from consumption to decline as health deteriorates, a phenomenon Finkelstein, Luttmer, and Notowidigdo (2013) term negative state dependence.

However, since many other goods and services, such as hospital stays (or OAAs or insulin in people with normal glucose regulation), are substitutes for good health (i.e., we derive greater benefit or enjoyment from them when we are sick), positive state dependence could be more likely or common (Zweifel et al., 2009, p. 93). This discussion suggests that the sign of any potential state dependence cannot be determined with reference to theory alone, and that the issue must be settled empirically (Finkelstein, Luttmer, & Notowidigdo, 2009, p. 116).

Further to this, Levy and Nir (2012) conclude that most studies, including their own, indicate that the marginal utility of wealth increases with health, implying negative state dependence. More recently, on the basis of an analysis of Health and Retirement Study data on 11,514 individuals aged 50 or older who are not in the labour force but have health insurance, Finkelstein et al. (2013) determine that a one-standard-deviation increase in the number of chronic diseases is associated with a 10-25% decline in marginal utility, providing further evidence of negative state dependence.

The formulation of the utility function is also dependent upon the definition of health status, which varies across studies. Galama et al. (2013), for example, define this as health capital (expressed in monetary terms); by contrast, Hall and Jones (2007) utilize expected life years, and Finkelstein et al. (2008) incorporate a binary variable that is equal to one when the individual is sick and zero otherwise. Following Levy and Nir (2012), this study defines health states in terms of people's preferences over those states, enabling application of HRQoL figures elicited from T2DM patients in prior research.

The reward function selected for the purposes of the individual decision model is given by the following expression, adapted from Levy and Nir (2012):

(14) $$u_t\left(f\left(h_t\right), c_t, \ell \quad \ell \quad \ell^{\nu}$$

This expression indicates that the decision-maker's reward (i.e., within-period utility) in the current period is given by the product of the health-related quality of life (HRQoL) associated with health state h_t and a standard constant elasticity of substitution (CES) utility function that includes levels of consumption and leisure enjoyed at time *t*. I offer the following observations concerning Equation (14):

- ❖ $f(\cdot)$ ranges from zero to one, with zero representing being deceased and one representing perfect health.[10]

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10 Some QoL scoring systems, including the EuroQol Five-Dimensional (EQ-5D) Questionnaire for the UK (results from which are incorporated into the UKPDS-OM2) allow for health states that are perceived to be worse than death (Alva, Gray, Mihaylova, & Clarke, 2014), range from -0.594 to 1.00

- $\rho = ((\sigma - 1)/\sigma)$, where $\rho \leq 1$ and $\rho \neq 0$, and where σ is the elasticity of substitution (see Section 3.4.2 below).

- α, which lies in the open unit interval, reflects preferences over consumption and leisure (see Section 3.4.3 below).

- γ denotes returns to scale; for the purposes of this thesis, we hereafter assume γ = 1, denoting constant returns to scale (Levy & Nir, 2012, p. 180; Nechyba, 2011, p. 126; Nicholson & Snyder, 2012, p. 319).

We can readily verify that the within-period reward function represented by Equation (14) is characterized by negative state dependence with respect to consumption and leisure as by differentiating the first-order partial derivatives with respect to $f(\cdot)$:

(15)
$$\frac{\partial^2 u_t\left(f\left(h_t\right), c_t, \ell\right.}{\partial c_t \partial f\left(h_t\right)} - \alpha c_t^{\rho-1}\left[\alpha c_t^{\rho} + (1-\alpha)\ell\right.^{1-\rho} \quad 0$$
$$\frac{\partial^2 u_t\left(f\left(h_t\right), c_t, \ell\right.}{\partial \ell} - (1-\alpha)\ell \quad \ell^{1-\rho}$$

(Harrison et al., 2009, p. 1026). Practically speaking, however, very few of the UKPDS-OM2 simulations generated HRQoL scores lower than zero.

3.4.2 Elasticity of substitution

The elasticity of substitution, denoted by σ, measures the curvature of the utility function (i.e., the percentage change in the ratio of consumption of two goods associated with a one percent change in the marginal rate of substitution between them along a utility function) (Varian, 1992, p. 13). One useful property of the CES utility function is its capacity to mimic a range of other functional forms by simply varying ρ (pp. 19-20):

- As ρ approaches 1, σ approaches ∞, producing a linear utility function that exhibits infinite substitutability between two goods.

- As ρ approaches 0, σ approaches 1, producing a Cobb-Douglas utility function. Cobb-Douglas utility functions exhibit weak separability, in that demand for one good is tied to consumption of a second good only to the extent that the latter affects how much income is available to purchase the former (Varian, 1992, pp. 150–151).

- As ρ approaches -∞, σ approaches 0, producing a Leontief utility function that exhibits perfect complementarity between two goods.

By default, however, the decision model assumes $\rho = 0$, which, as just noted, means the reward function essentially mimics the attributes of a Cobb-Douglas function. To probe some of the potential implications of this choice, I briefly summarize how ρ impacts optimal decision-making in the context of a simple labour supply model in which personal consumption and leisure are financed from labour market earnings (Table 4); to be clear, these results are included primarily for the purposes of illustration, since the optimization problem underpinning the decision model is significantly more complex:

Table 4: Comparing consumption and leisure demand functions and labour supply functions and sensitivity to price and wage variability in the context of a simple labour supply model

Variable	**Demand/supply functions**		**Partials**					
			P_c			**w**		
	$\rho \neq 0$	**$\rho = 0$**	**ρ < 0**	**ρ = 0**	**(0, 1)**	**ρ < 0**	**ρ = 0**	**(0, 1)**
Consumption	$\left[\frac{\Omega w}{P_c}\right] \times \frac{1}{1+\left[\frac{\alpha}{1-\alpha}\right]^{\frac{1}{\rho-1}}\left[\frac{w}{P_c}\right]^{\frac{\rho}{\rho-1}}}$	$\frac{\alpha \Omega w}{P_c}$	Varies	-	-	Varies	+	+
Leisure	$\Omega \times \frac{1}{1+\left[\frac{1-\alpha}{\alpha}\right]^{\frac{1}{\rho-1}}\left[\frac{P_c}{w}\right]^{\frac{\rho}{\rho-1}}}$	$(1-\alpha)\ \Omega$	-	0	+	+	0	-
Labour supply	$\Omega \times \frac{1}{1+\left[\frac{\alpha}{1-\alpha}\right]^{\frac{1}{\rho-1}}\left[\frac{w}{P_c}\right]^{\frac{\rho}{\rho-1}}}$	$\alpha\, \Omega$	+	0	-	-	0	+

The upshot of Table 4 is that substitutability or complementarity of consumption and leisure can significantly affect resource allocation decisions. For instance, when consumption and leisure are readily substitutable for each other (i.e., $0 < \rho < 1$), wage increases tend to reduce the demand for leisure while increasing the individual's supply of labour, whereas when consumption and leisure complement one another (i.e., $0 > \rho$), the opposite occurs. When consumption and leisure are neither (gross) complements nor (gross) substitutes (i.e., $\rho = 0$), by contrast, demand for leisure and supply labour are both unaffected by wage changes; this is tied to the weak separability of the Cobb-Douglas utility function (Varian, 1992, pp. 150–151), and occurs because in this unique case substitution and income effects precisely cancel each other out.

In summary, therefore, smaller values of ρ are indicative of a preference for joint consumption of two goods, while larger values reflect a degree of comfort with imbalanced consumption bundles. As part of the sensitivity analysis in Section 4.2.1 in Chapter 4, I implement a two-way sensitivity analysis that examines how decision-making and individual well-being vary with ρ (considering values that include -10.00, 0.00, and 1.00) and the price of consumption (considering values that include 0.50, 0.75, 1.00, 1.50, and 2.00).

3.4.3 Preferences over consumption and leisure

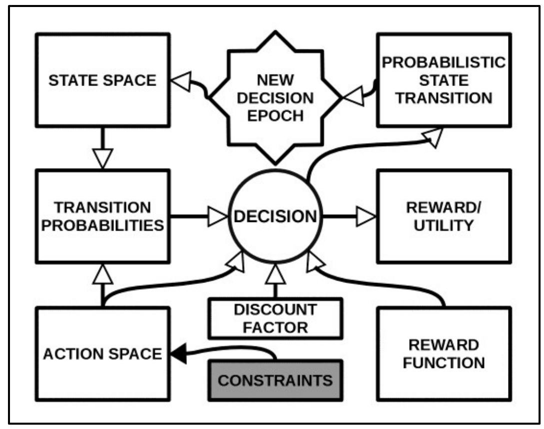
α in Equation (14) is essentially a distribution parameter reflecting the relative strengths of the individual's preferences over consumption and leisure, where $0 \leq \alpha \leq 1$ (K. J. Arrow, Chenery, Minhas, & Solow, 1961, p. 230; Nechyba, 2011, p. 126). By default, the decision model assumes $\alpha = 0.50$, which is to say they weigh consumption of each good equally. However, since we would expect preferences for consumption and leisure may to vary widely among individuals, as part of the sensitivity analysis I consider a range of values for α, including 0.00, 0.25, 0.50, 0.75, and 1.00.

3.4.4 Preferences over health states

As noted in Section 2.2, it is assumed that T2DM is the only condition that affects health. Furthermore, I assume that although the organ and tissue damage that leads to the complications characteristic of T2DM may begin to accumulate during prediabetes, this does not generally manifest in ways that detract from the individual's HRQoL. Consequently, individuals in the healthy/prediabetic state are assigned an HRQoL score of one.

HRQoL scores for individuals with diagnosed T2DM are derived from simulations undertaken using the UKPDS-OM2, which are in turn driven by parameters (i.e., initial utility levels and HRQoL tariffs) obtained from Alva et al. (2014) and Lung et al. (2011). More specifically, the HRQoL scores awarded to an individual immediately following each decision epoch reflect the expected progression of T2DM up to that point, based on observations of outcomes experienced within a large cohort of individuals with identical characteristics (i.e., gender, ethnicity, age and duration of T2DM) who have made the same decisions regarding the management of their condition. Further details regarding the derivation of the HRQoL scores are included in Section 3.6.2.

3.5 Constraints



The action space in the decision model is constrained in two fundamental ways.

- The decision-maker may not spend more in any period on food, medication, LTPA participation and/or other goods and services than they can earn by supplying labour in the marketplace or that they receive through the Employment and Income Assistance (EIA) Program or retirement income. While employed, people must also make annual CPP/EI contributions, and set aside money for retirement through an enforced savings mechanism, the features of which I describe below. Moreover, all employment income and most retirement income is subject to federal and provincial taxes.

- ❖ Time set aside for work, leisure, and health-promoting activities, or tied to the individual's state and thus non-discretionary (e.g., time allocated to sleep or lost to illness), may not exceed the amount available in any decision epoch.

I pause here to elaborate concerning the operationalization of the constraints within the decision model, since employing numerical solution techniques precludes approaches that would accompany the application of analytical methods. Where it is necessary to prevent an individual from taking a course of action that would violate the income and/or time constraints or is otherwise non-permissible, the model is programmed to override the calculation of the reward function and assign a penalty, thereby rendering these actions unappealing and motivating decision-makers to "live within their means" (Fackler, 2011, p. 18).

I consider below the model's conceptualization of the retirement decision, which illustrates how the program exploits the calculation of rewards to compel patients to make some choices and not others. As discussed in detail in Section 3.6.4, the model assumes individuals have the option of withdrawing from the labour force at any time once they've reached the standard age of retirement (i.e., age 65). However, the model regards the retirement decision as irreversible, and effectively imposes retirement upon those who are unemployed at age 65 or who subsequently experience unexpected job loss.

Figure 3 below represents this scenario using a decision tree, which preserves most of the essential features of the actual model as they relate to the retirement decision. Briefly, at a given point in time, a person who has reached the standard age of retirement has the option of continuing to work or retiring, as denoted by the square. In this simple example, there are no health states, and the retirement decision is a once-and-for-all choice which, once made, initiates a series of probabilistic employment state transitions (as denoted by the dark circles, which represent Markov processes). Within a given process, for each cycle, a random draw from a predefined probability distribution (denoted by the light circles) determines the state the individual occupies in the subsequent period (denoted by the labels adjoining the shaded triangles), and his or her within-period reward, which is presented in the table:

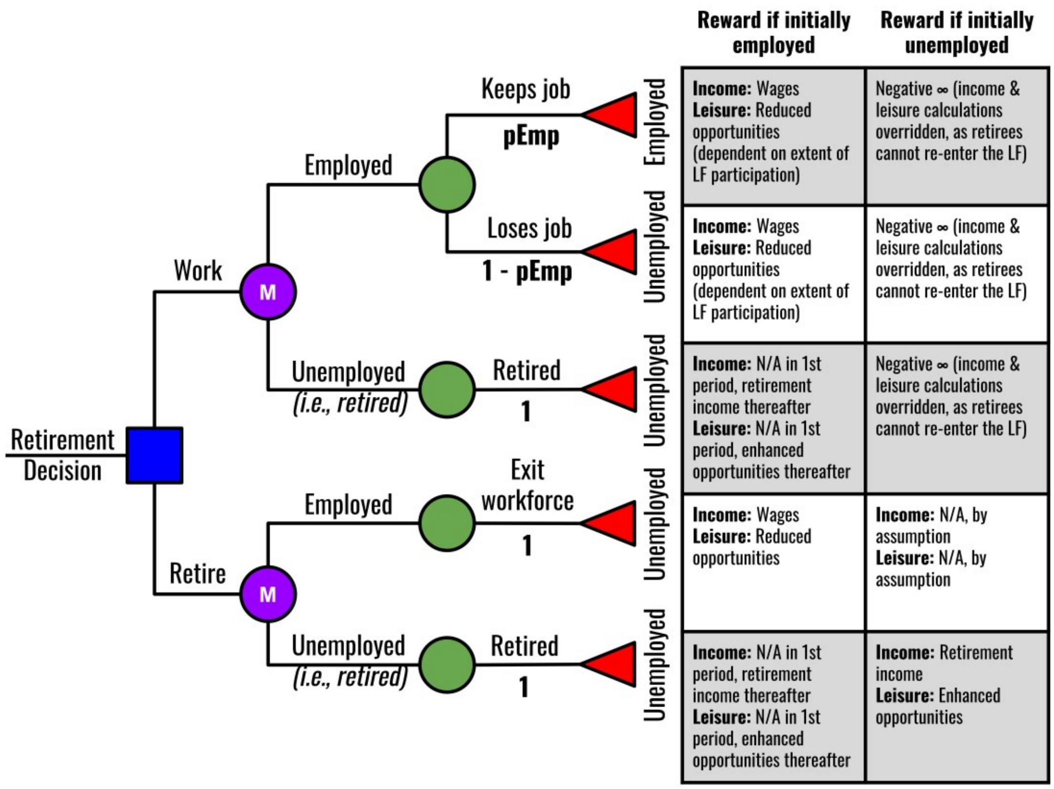


Figure 3: Diagrammatic representation of the retirement decision for individuals age 65 and older

I draw attention here to the rewards. If employed during a given cycle, a person's utility is calculated by determining how much consumption and leisure their choice entitles them to enjoy (see below); these values then serve as inputs into a reward function, such as the one referenced in Section 3.4. From a modelling perspective, the issue is how to enforce the irreversibility of retirement. As the second column in the table indicates, the solution is to make rewards state-dependent and, more specifically, to threaten substantial penalties for those who would otherwise be inclined to "unretire".

As noted, the model applies precisely the same technique to prevent economic agents from making any choices that violate income or time constraints, or which are otherwise inconsistent with its underlying assumptions.

3.5.1 Income constraints

The income constraint, as represented by Equation (16), states that an individual's consumption ($p^c c_t$) may not exceed his or her income (i.e., Y_t), net of deductions (i.e., $Deduct_t$, which denotes federal and provincial taxes, CPP and EI contributions, and retirement savings) and expenditures on goods and services that affect health outcomes (i.e., $HealthExp_t$, which denotes dietary and pharmaceutical expenditures and spending related to LTPA participation); for reasons already discussed, the framework does not currently permit the individual to borrow against future income or to choose when and how much to save:

$$(16) \quad p^c c_t = Y_t - Deduct_t - HealthExp_t$$

I now outline the components of Equation (16). As Section 4.3 below presents separate equations for each such component, the ensuing discussion will be largely informal in nature.

Income

The model incorporates the assumption that household income (denoted by Y_t) is generally derived from at most one of the following sources at any time, namely

- wages and salaries (i.e., labour income);
- Employment and Income Assistance (EIA);
- or, retirement income, including CPP, Old Age Security (OAS), the Guaranteed Income Supplement (GIS).

In addition, starting at age 65 people may also begin availing themselves of assets they accumulated over their careers, irrespective of the timing of retirement.

As just noted, the model does not permit borrowing against future income and does not incorporate EI programming. I also assume that income flows from all sources remain constant in real terms, and that the design of provincial and federal social assistance and retirement programs and systems of taxation do not change over time.

Wages and salaries

The model assumes a person's ability to generate employment income depends on hours worked, age, gender, and education. Labour market earnings are derived using data on total (gross) employment income collected for Manitoba from the 2011 National Household Survey (NHS), which have been extrapolated to 2018 by applying the Consumer Price Index (Table 5):

Table 5: Gross employment income for Manitobans working full-time, full-year (49-52 weeks), by gender, age, and level of educational attainment (2017 dollars)

Age	No certificate, diploma or degree		High school diploma or equivalent		Post-secondary certificate or diploma below bachelor level		University certificate, diploma, or degree at bachelor level or above	
	Male	Female	Male	Female	Male	Female	Male	Female
25	$38,057	$31,341	$43,653	$34,699	$51,488	$39,176	$56,525	$57,085
35	$43,653	$35,818	$53,727	$38,057	$60,443	$45,892	$81,710	$75,554
45	$51,488	$35,818	$55,966	$43,653	$64,920	$48,130	$89,545	$77,233
55	$43,653	$33,579	$50,369	$44,773	$66,599	$48,130	$89,545	$81,710
65	$39,176	$31,900	$35,258	$29,662	$48,690	$41,415	$70,517	$68,278
*75	$29,382	$23,925	$26,444	$22,246	$36,518	$31,061	$52,888	$51,209
*85	$19,588	$15,950	$17,629	$14,831	$24,345	$20,707	$35,258	$34,139
*94	$10,773	$8,773	$9,696	$8,157	$13,390	$11,389	$19,392	$18,776

* **NOTE:** Extrapolated from the 2011 NHS data, by assuming productivity declines at an annual rate of 2.5% after age 65.
Source: Statistics Canada (2014, 2018c), excepting values for individuals older than 65.

While economic theories of retirement posit that labour force productivity should decline towards the end of an individual's working life, I did not identify a valid point estimate of the magnitude of this effect (see page 176 in Section 3.6.4 for a brief overview of this literature). As such, I assume employment income declines at an annual rate of 2.5% after age 65, but consider a range of plausible values (i.e., 0.0%, 1.0%, 5.0%, and 10.0%) for the sensitivity analysis, results for which are presented in Section 4.2.4 in Chapter 4.

EIA

Manitoba's EIA Program provides financial assistance to Manitoba households that would otherwise be unable to support themselves (Province of Manitoba Department of Families, 2017a, 2017b). I assume that individuals younger than 65 who are unemployed in any period qualify for EIA and the maximum Rent Assist amount, and, since decision-making in the model is undertaken by single-unit households (i.e., no partner or dependents), that they fall under the General Assistance Category. EIA benefits for unemployed individuals are set equal to $806 per month, reflecting the structure of the EIA program as of July 1st, 2017 (Province of Manitoba Department of Families, 2017a).

Retirement income

Individuals aged 65 or older who voluntarily withdraw from the labour market begin earning their CPP/Québec Pension Plan, OAS, and GIS in the same period the choice is made. They are also eligible to begin liquidating personal assets they accumulated earlier in life. Derivation of retirement income is also governed by the following simplifying assumptions:

- Individuals aged 65 or older who are separated from their positions will automatically begin earning retirement income in the subsequent period.[11]

- All public sources of retirement income (including the CPP/Québec Pension Plan, which in principle can be accessed as early as age 60) become available at age 65 (Ontario Securities Commission, 2017). No actuarial adjustment is applied (Employment and Social Development Canada, 2017a). People are not required to take their public pensions at age 65, but they cannot work and earn CPP/OAS/GIS concurrently.

- CPP, OAS and GIS payment amounts are based upon gross employment earnings accumulated by a healthy individual who works full-time during each of the 39 years prior to age 65.[12] This implies that although decision-makers may not necessarily earn the maximum payment amount under the CPP, their

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11 Because job loss is assumed to take place the instant before the next decision epoch, people earn a full year's worth of employment income in the period this occurs.

12 Adjusted pensionable earnings use the average of the maximum pensionable earnings for the five years between 2013 and 2017, inclusive (Runchey, 2018). Average CPP payment amounts are generally much less than the maximum (Employment and Social Development Canada, 2017a). These amounts are based on up to 39 years with the highest levels of recorded income (Employment and Social Development Canada, 2016a; Heinzl, 2017). 2011 NHS data suggests that median annual wages and salaries between the ages of 25 and 65 are invariably higher than between the ages of 15 and 24, and since a person's CPP pension does not reflect changes in their working hours or gaps in employment, the 39 years immediately prior to age 65 are used as the basis for their benefit.

pension does not depend on changes in working hours or employment gaps and does not reflect productivity losses attributable to T2DM.

I defer assigning specific values to each source of retirement income to the next section, where I report both this and income derived from liquidation of personal assets in a single place (see Table 6 on page 120 below).

Personal assets

Beginning at age 65, people can begin drawing down the assets they accumulated earlier in life. The model distinguishes accumulated assets from other sources of retirement income in that there is no requirement to withdraw from the labour force before accessing the former.

Asset accumulation in the model takes the form of an enforced savings mechanism that automatically allocates a fixed proportion of gross employment income (10%, by default) to a personal savings account, which accrues interest at a predetermined rate (3%, by default), but from which the individual cannot withdraw prior to the standard age of retirement. Upon reaching age 65, a fixed amount is automatically withdrawn each year, irrespective of employment status. The disbursement mechanism is designed to ensure an individual's savings are sufficient to support them through to the end of their projected life expectancy at birth (Statistics Canada, 2018a; Tallarida, 2015, pp. 211–213).

Table 6 reports annual pre-tax retirement income for decision-makers with varying combinations of individual characteristics:

Table 6: Pre-tax annual retirement income, by gender, age, level of educational attainment, and income source (2017 current dollars)

Level of educational attainment	Income source	Male		Female	
		Ages 65-79	Ages 80+	Ages 65-83	Ages 84+
No certificate, diploma or degree	Public pension	$17,753	$24,633	$15,297	$23,405
	Personal assets	$25,640	$0	$16,614	$0
	Total	**$43,393**	**$24,633**	**$31,912**	**$23,405**
High school diploma or equivalent	Public pension	$19,343	$25,428	$16,803	$24,158
	Personal assets	$29,667	$0	$19,178	$0
	Total	**$49,010**	**$25,428**	**$35,981**	**$24,158**
Post-secondary certificate or diploma below bachelor level	Public pension	$20,183	$25,848	$18,024	$24,769
	Personal assets	$35,033	$0	$21,754	$0
	Total	**$55,216**	**$25,848**	**$39,778**	**$24,769**
University certificate, diploma, or degree at bachelor level or above	Public pension	$20,396	$25,955	$20,396	$25,955
	Personal assets	$44,901	$0	$34,558	$0
	Total	**$65,297**	**$25,955**	**$54,954**	**$25,955**

Source: Author's calculations, based upon data published by Employment and Social Development Canada (2017a), EY (2018), Service Canada (2017), and Statistics Canada (2014, 2018a), and formulas presented in Tallarida (2015, pp. 211–213)

Two points bear noting. First, the marked decline in retirement income beginning at age 80 for men and age 84 for women reflects the eventual exhaustion of personal savings, which, as just noted, is timed to correspond with average life expectancy for each gender (Statistics Canada, 2018a). Second, exhaustion of personal savings is to some extent offset by increases in income from public pensions, because alternate sources of retirement income may result in OAS and GIS payment clawbacks; in the case of OAS, for example, recipients are required to repay 15% of every dollar in excess of predefined annual thresholds ($74,788 in May 2019) (Service Canada, 2018).

Deductions from income

Deductions from household income include federal and provincial taxes, CPP and EI contributions, personal savings, and efficiency losses.

Federal and provincial taxes

Employment income is subject to provincial and federal taxes, as are CPP and OAS payments (Employment and Social Development Canada, 2017b; Government of Canada, 2018; Service Canada, 2017), and any amounts withdrawn from a person's accumulated savings. Neither GIS nor social assistance payments constitute taxable income (Canada Revenue Agency, 2018; TurboTax Canada, 2016). The model presently employs the tax brackets and marginal tax rates in place for the 2018 tax filing system (EY, 2018).

Of note, the model assumes taxes owing on employment income are calculated *after* deducting personal savings. In this way, asset accumulation resembles the process of contributing to a Registered Retirement Savings Plan (RRSP).

CPP and EI contributions

People must contribute to both CPP and EI for as long as they are working, even though the model does not currently permit people to avail themselves of EI programming during bouts of unemployment. CPP (contribution) and EI (premium) rates and CPP/EI maximums and exemptions are set to the levels prevailing during 2018 (Canada Revenue Agency, 2017b, 2017c; EY, 2018).

Personal savings

As already mentioned, the model incorporates an enforced savings mechanism, whereby a fixed proportion of the gross employment income (10%, by default) a healthy person would earn working full-time hours,[13] is used to accumulate assets to finance retirement. This mechanism ceases to operate once a person enters their 66th year of life and begins drawing down these assets. The model calculates resources allocated to asset accumulation by multiplying the values in Table 5 by the savings rate.

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13 This assumption is again necessitated by the challenges involved in recording past events or decisions. To realistically model asset accumulation in this context would require introducing enough states to account not only for any breaks in employment and any periods of part-time employment, but also for T2DM duration and adherence history *during every decision epoch* (which, as noted below, determine efficiency losses attributable to absenteeism and presenteeism).

Efficiency losses

The model assumes symptoms associated with T2DM and/or its complications may limit a person's ability to perform day-to-day activities. When these symptoms are experienced at work, they can affect a person's capacity to generate income by manifesting in workplace absenteeism (i.e., absences from work due to illness or health investment, such as receipt of medical care) and presenteeism (i.e., reduced on-the-job productivity).

Tabulation of efficiency losses is involved, and I defer a detailed methodological discussion to Section 3.5.3 below. A brief summary of the approach is as follows:

- ❖ Absenteeism is tied to the simulated accumulation of diabetic complications in patient cohorts using the UKPDS-OM2, which in turn draws from estimates reported in Sørensen and Ploug (2013). People can mitigate the impact of absenteeism on labour market earnings by taking advantage of paid sick days, but absences exceeding allotted sick days are unremunerated.
- ❖ Presenteeism is modelled based upon results presented in Lavigne et al. (2003). Presenteeism does not directly influence the wage rate; rather, the model conceptualizes reduced capacity at work in terms of equivalent hours of lost productivity. Employers cannot fully adjust remuneration to account for

reduced productivity (e.g., due to imperfect monitoring mechanisms), so losses attributable to presenteeism are shared between workers and firms.

Summary

Because an individual's capacity to generate labour market income is tied not only to their personal characteristics but also their circumstances at any given time, it is not feasible to present here all the values incorporated into the decision model, even in tabular format. However, Table 30 and Table 31 in Appendix A report net employment income for healthy full- and part-time workers, by gender, age and level of educational attainment (i.e., after accounting for taxes, CPP/EI contributions, personal savings, and age-related productivity decline). These figures do not account for absenteeism and presenteeism accompanying T2DM, so they should be regarded as the maximum amount of employment income decision-makers can expect to generate, given their age and fixed attributes.

There are no deductions from EIA income in the decision model.

Table 7 complements Table 6 on page 120, reporting annual retirement income after deduction of income taxes:

Table 7: Net annual retirement income, by gender, age, and level of educational attainment (2017 current dollars)				
Level of educational attainment	**Male**		**Female**	
	Ages 65-79	**Ages 80+**	**Ages 65-83**	**Ages 84+**
No certificate, diploma or degree	$34,758	$22,838	$26,462	$22,244
High school diploma or equivalent	$38,684	$23,223	$29,402	$22,608
Post-secondary certificate or diploma below bachelor level	$42,826	$23,426	$32,146	$22,904
University certificate, diploma, or degree at bachelor level or above	$49,555	$23,477	$42,652	$23,477
Source: Author's calculations, based upon data published by Employment and Social Development Canada (2017a), EY (2018), Service Canada (2017), and Statistics Canada (2014, 2018a), and formulas presented in Tallarida (2015, pp. 211–213)				

Health expenditures

Income remaining after taxes CPP/EI contributions and personal savings retirement is invested in health or used to finance consumption; I focus here on the former class of expenditures. It is important to recognize that because the decisions to adhere to LTPA, healthy eating, and prescribed courses of pharmacotherapy are dichotomous in the model, a person does not purchase units of each, but rather incurs one cost if they choose to adhere and a different (typically lower) cost otherwise:[14]

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[14] This notation remains useful, however, because it highlights opportunities to extend the model to incorporate gradations of adherence.

- *LTPA.* The model presently assumes there are no financial outlays associated with participation in LTPA.

- *Pharmacotherapy.* I estimate the cost of medication adherence by consulting with a practicing Manitoba pharmacist to construct profiles that reflect the types of drugs and corresponding dosages patients might require as their condition progresses. This data was then integrated with information about the structure of Manitoba's provincial drug benefit program (Manitoba Health, Seniors and Active Living, 2017a, 2017b, 2017c) and figures reported by Magnasson et al. (2018). A detailed overview of this exercise is included in Appendix C, but high-level results are as follows:

    - In the absence of private or public insurance coverage

        - an individual with recently diagnosed with T2DM with no complications would spend $922.68 per year on medication;

        - an individual who has had T2DM for many years (a decade or more) but has generally managed their condition well is expected to pay $3,990.68 each year for their medications;

- and, someone who has had T2DM for many years (a decade or more) but has generally managed their condition poorly is expected to pay $5,716.40 each year for their medications.

➢ The model assumes people can manage the impact of pharmacotherapy on household finances by participating in the Manitoba Pharmacare Program, a provincial drug benefit program characterized by income-based deductibles beyond which all eligible costs are Program-subsidized.[15]

- Information regarding program structure was obtained from the province's website for the 2017/18 benefit year (Manitoba Health, Seniors and Active Living, 2017a).

- These rates were then applied to the household income figures compiled in Section 3.5.1 to calculate Pharmacare deductibles for individuals with varying combinations of personal characteristics and employment and health status.

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15 The Program establishes a deductible based on a household's Adjusted Total Family Income, defined as the sum of the income of the application and his or her spouse, minus $3,000.00 for the spouse and each dependent under 18 years of age; once the household has paid out-of-pocket for drug expenditures in excess of the deductible, Pharmacare will cover 100% of any additional expenses (Manitoba Health, Seniors and Active Living, 2017a).

- Finally, deductibles were compared with the calculated annual costs of pharmacotherapy to determine out-of-pocket expenditures, with actual expenditures being the lower of the two.

- As just noted, Pharmacare deductibles are tied to income, which, for those who are employed, depends on how long a person has lived with T2DM and how they have managed it (i.e., since this determines how much employment income is lost to absenteeism and presenteeism). Because of the complexity of these relationships, it is impractical to present final drug expenditures here for all scenarios.

❖ *Meal preparation*. Household expenditures required to finance healthy and unhealthy eating habits were derived from a costing exercise designed and implemented by the author, details regarding which are presented in Appendix B. Of note, the results of this procedure, which are presented in Table 8, do not support the assertion that healthy diets necessarily cost more than less healthy alternatives, and, indeed, suggest that the converse is often true. This occurs for two reasons:

  - First, the unhealthy diet involves significantly higher caloric intake, and would therefore necessitate entail a larger financial outlay even if the person consumed many of the same foods and beverages.

- Second, one can often achieve large improvements in dietary quality without increasing spending (e.g., by reducing spending on red and processed meat products, while purchasing more nuts, soy, and beans, or more whole grain products) (Bernstein et al., 2010; Carlson, Dong, & Lino, 2014; Katz et al., 2011).

Table 8: Annual costs of healthy and unhealthy diets, by gender, age and ethnicity (2017 current dollars)

Age	Diet	Afro-Caribbean		Asian-Indian		Caucasian	
		Male	Female	Male	Female	Male	Female
25-44	Healthy	$4,355.39	$3,164.41	$4,164.50	$2,987.79	$4,377.57	$3,161.73
	Unhealthy	$6,545.94	$5,123.37	$6,202.93	$4,896.62	$6,586.18	$5,119.45
45-64	Healthy	$3,938.56	$2,779.81	$3,747.45	$2,594.10	$3,960.77	$2,776.67
	Unhealthy	$6,061.50	$4,835.85	$5,723.48	$4,612.41	$6,101.14	$4,832.10
65-94	Healthy	$3,476.27	$2,331.79	$3,274.70	$2,144.55	$3,498.51	$2,328.63
	Unhealthy	$5,528.39	$4,524.08	$5,209.97	$4,300.98	$5,567.41	$4,520.33

Source: Author's calculations, based upon sources referenced in Appendix B

Consumption

Equation (16) implies that household income not paid to government in the form of income tax, CPP or EI contributions, or allocated to the purchase of health-promoting goods and services, is available for household consumption. The model expresses consumption in terms of units. Of note is that although the model nominally sets the price of a unit of consumption to $1.00, the sensitivity analysis in Chapter 4 (Section 4.2.1) examines how individual choices and well-being vary with this parameter (using values that include $0.50, $0.75, $1.00, $1.50 and

$2.00) under varying assumptions about the elasticity of substitution between consumption and leisure.

3.5.2 Time constraints

Equation (17) summarizes the decision model's conceptualization of the allocation of time to various activities; briefly, the model expresses the amount of leisure an individual may enjoy during any decision epoch as the difference between the total amount available (i.e., Ω), the amount tied to his or her current state (and thus beyond their ability to adjust, at least in the short run) (i.e., T^{NDisc}), and the amount they allocate to all non-leisure activities (i.e., T^{Disc}):

(17) $$\ell \qquad {}^{isc} - T_t^{Disc}$$

As above, I offer here a verbal description of the components of Equation (17), deferring a more formal presentation to Section 4.3.

Total available time

Since each period is one year in length, there are a total of 8,736 hours available for any activity.

Time associated with non-discretionary activities

As just noted, non-discretionary activities are those tied to the state the person occupies during a decision epoch; because the person's current state is given, these are effectively mandatory. Non-discretionary activities include:

- ***Sleep.*** I assume all decision-makers allocate eight hours per day to sleep, equivalent to 2,920 hours per year.

- ***Illness.*** The decision model assumes T2DM and its complications produce symptoms that affect a person's ability to perform the activities of daily living, further supposing that time spent bedridden or functioning at reduced capacity can be condensed into a single measure that reflects equivalent hours of lost productivity. Since a detailed methodological discussion of the calculation of this lost productive time (LPT) is presented in Section 3.5.3 below, here I simply summarize the central features of my approach:

  - Sørensen and Ploug (2013) and Lavigne et al. (2003) focus, respectively, on workplace absenteeism and presenteeism. However, illness experienced outside of work hours also has important implications for how people spend their time. As such, the model extrapolates total time lost to illness from the results observed in these studies.

- For individuals who are unemployed or retired, all time lost to illness is deducted from the total available for discretionary activities and leisure (by definition, non-discretionary activities must be sustained, irrespective of health status).

- For individuals who are employed, sick time is segmented into that experienced while they should be working, and that occurring at other times. This segmentation reflects the observation that, for example, a person cannot necessarily make up for missed work by simply reallocating some of their leisure time (or vice versa). As noted in Section 3.5.1, however

  - decision-makers can effectively convert a set number of workplace absences each year into work days by taking advantage of paid sick leave (these become classified as work because they are remunerated), but the hours-equivalent of absences in excess of this number become unavailable for any activity in the decision epoch in which they occur;

  - and, reduced on-the-job productivity (i.e., presenteeism) does not affect how the person allocates time (the individual is technically still at work) but *can* influence labour market earnings, while the hours-equivalent of reduced productivity outside the workplace is simply deducted from the total available for non-work activities during the decision epoch under consideration.

- ***Labour market activities.*** The model assumes individuals younger than 65 must choose to work either full-time or part-time if they occupy the "employed" state when their choice is made and must search for work if unemployed at that time; if they are 65 or older, by contrast, they may sidestep these activity restrictions by retiring:

  - *Job search (if unemployed).* The EIA program requires recipients to search for work (Province of Manitoba Department of Families, 2017a, 2017c). Drawing from the results of an analysis conducted by the Organisation for Economic Co-operation and Development (2015) with data from the Employment Insurance Coverage Survey, I assume unemployed individuals invest 9.5 hours per week engaged in this activity, or 494 hours per year (page 142).

  - *Work (if employed).* Individuals younger than 65 who are employed must choose to work either full-time or part-time. Assuming there are 250 eight-hour workdays in a year and that part-time work entails precisely half the level of commitment expected of full-time employees, this implies they must allocate at least 1,000 hours to labour market participation annually.

- ***Other non-discretionary activities.*** The model is equipped to require decision-makers to allocate time to health-related activities, reflecting that it is in many real-world circumstances literally impossible to allocate no time to eating or to some form of physical exertion, however limited it may be:

  - *LTPA and medication adherence.* Notwithstanding the previous statement, I assume the minimum amount of time the person must dedicate to physical activity and pharmacotherapy (i.e., in the case of non-adherence) is zero.

  - *Meal preparation/consumption.* The costs associated with meal preparation include the time required to engage in such activities as meal planning, shopping, cooking, and cleanup. Based on tabulations undertaken using 2015 General Social Survey microdata, I assume 30 minutes per day (the sample median) constitutes a reasonable estimate of the minimum amount of time needed to engage in these activities. I further assume such a diet consists largely of processed and ultra-processed items or food consumed away from home that involve minimal investment in terms of time but that are also inconsistent with a healthy lifestyle (i.e., reflect non-adherence to healthy eating habits).

Time associated with discretionary activities

Discretionary activities relate to the nature and scale of labour market involvement and to activities that influence health outcomes:

- ***Labour market activities.*** While employed individuals who have not yet reached the standard age of retirement must commit a minimum amount of time to labour market participation (which is again non-discretionary), they typically exercise the option of expanding their level of commitment; individuals aged 65 or older also have the option of permanently withdrawing from the labour market through retirement:

  - *Work (if employed).* As noted above, individuals younger than 65 who are employed during any decision epoch must at minimum allocate 1,000 hours of their time to generating income in the labour market each year, which, for modelling purposes, we consider representative of most part-time employment opportunities. However, people may at their discretion increase their supply of labour to 2,000 hours per year, which, conceptually, could represent commitment to either a single full-time position or to multiple part-time positions.

- *Retirement.* Individuals who have reached age 65 may continue to work either part-time or full-time hours but are not required to do so. As regards the allocation of time, the effect of retirement is to altogether free the individual from the requirement to work or search for work. Assumptions guiding the modelling of the retirement decision are referenced elsewhere (see page 110 above and Section 3.6.4 below) and not repeated here.

- ***Time dedicated to health-related activities.*** While allowing for the possibility that it is virtually impossible to avoid allocating time to certain activities that affect health, the model assumes healthy lifestyle choices typically necessitate an incremental investment of time above and beyond these minimum levels:

  - *LTPA.* Adherence to LTPA involves compliance with Canadian Society for Exercise Physiology recommendations to engage in 150 minutes of moderate-to-vigorous-intensity aerobic physical activity (i.e., ≥ 3 METs) per week (i.e., 130 hours per year).

  - *Time allocated to administering medications.* I assume individuals with T2DM need minimal amounts of time to self-administer medications and engage in other activities consistent with adherence to pharmacotherapy.

- *Time allocated to meal preparation.* Consistent with the discussion in Section 2.5.1 in Chapter 2 (page 43) and, in particular, the results presented in Russell et al. (2005), I assume adhering to a healthy diet requires people to invest an *additional* 60 minutes per day (365 hours per year) in meal preparation above and beyond the time needed to maintain an unhealthy diet. This implies healthy eating habits entail an overall commitment of 90 minutes each day (547.5 hours per year), which includes planning, the procurement and processing of ingredients, the actual ingestion of food and beverages, and clean up.

Time allocated to leisure

Equation (17) implies that all time not allocated to the above activities is available to engage in leisure, which the model expresses in terms of hours per year.

3.5.3 Modelling the effect of illness on the allocation of household income and time

One important insight from Grossman's (1972) seminal model of health investment is that bouts of illness not only directly detract from well-being, but may also reduce the time available to engage in a range of activities, such as working, engaging in home production, and making investments in preventing future illness. The decision model incorporates this insight into the structure of the optimization problem, but also builds upon it in several ways.

First, the decision model conceptualizes the evolution of health status in terms of state transitions rather than as accumulation or depreciation of health capital, so a new approach is required to articulate how healthy days are generated (and, equivalently, how sick days are minimized).

Second, the approach outlined here acknowledges that not all sick days are alike. Just as the severity of an illness can vary widely, so too can the extent to which it affects an individual's capacity to perform the activities of daily living. This thesis conceptualizes the impact of sick days on productivity as a point on a spectrum ranging from minor inconvenience to incapacitation. When illness affects attendance and performance in workplace settings, this is known as absenteeism and presenteeism, respectively (Koopmanschap, Burdorf, & Lötters, 2013); however, the model recognizes that the health-related factors underlying these phenomena are also likely to affect the individual outside the workplace. This thesis draws inspiration from an emerging literature that combine estimates of productivity losses attributable to absenteeism and presenteeism into a single value (Lavigne et al., 2003; Stewart et al., 2007; Stewart, Ricci, Chee, &

Morganstein, 2003), which is then deducted from the time available to generate income in the labour market as well as to engage in non-work activities.

Third, this approach recognizes that productivity losses are often not borne entirely by workers with T2DM, and that it is more reasonable to assume that these losses are generally divided between workers and employers, as, for instance, is the case when workers have access to paid sick days and/or or short- or long-term disability programming, or when they function at diminished capacity at work. From an economic standpoint, it is important to acknowledge the distribution of the value of lost productivity between these two groups because of how this may influence both individual and firm decision-making.

Impact on workplace absences

In the current context, absenteeism refers to days of work missed due to the symptoms associated with T2DM and/or its complications and co-morbidities. Selection of values for model parameters that relate to the impact of T2DM on absenteeism is undertaken by imposing the following assumptions:

- ❖ Healthy or prediabetic workers do not experience absenteeism due to illness.
- ❖ Among individuals with T2DM who have never experienced complications, it is assumed that the lower end of the range presented in Breton et al. (2013)

(i.e., two days) is a reasonable ballpark estimate of the excess burden of absenteeism relative to healthy or prediabetic workers, and which could reflect bouts of illness attributable to hypoglycemic events or complications associated with influenza (Canadian Diabetes Association Clinical Practice Guidelines Expert Committee, 2013b; US CDC, 2017b).

- ❖ Among individuals who are experiencing or previously did experience complications, the decision model uses point estimates of the excess burden of absenteeism compiled by Sørensen and Ploug (2013) (presented in Table 9). I exploit the UKPDS-OM2's capacity to track medical costs attributable to treatment and diabetic complications, noting this can be readily adapted to track the accumulation of workplace absences. This is made possible by the fact that, as with the cost and utility parameters incorporated into the UKPDS-OM2, the figures in Sørensen and Ploug (2013) are broken down by complication type as well as whether the complication occurred in this or a prior year.[16]

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[16] It should be recognized, however, that not all complications incorporated into the UKPDS-OM2 were studied by Sørensen and Ploug (2013), and vice versa, and that there appear to be slight differences in how some complications are defined (this is difficult to gauge because complications are defined according to the 9th and 10th editions of the International Classification of Diseases, respectively).

Table 9: Incremental days absent due to diabetes-related complications for individuals in the workforce (point estimates)		
Complication	**First year of complication**	**Subsequent years**
Angina pectoris	54.7	14.9
Peripheral vascular disease	65.2	19.5
Ischaemic stroke	87.9	34.1
Heart failure	73	6.1
Renal disease	78.6	21
Uninfected ulcer	83.1	45.6
Infected ulcer	46.2	10.4
Neuropathy	44.9	16.8
Amputation	104.4	35.5
Source: Sørensen and Ploug (2013, p. 6)		

Impact on workplace productivity

This thesis calculates the impact of T2DM on workplace productivity using results obtained by Lavigne, Phelps, Mushlin, and Lednar (2003), which include the following:

❖ T2DM itself is not associated with significantly higher efficiency losses among individuals in the sample, but efficiency is reduced by the equivalent of 1.08 hours per month for each year elapsed since diagnosis (which could conceivably reflect the gradual onset of microvascular and macrovascular complications). The rate of productivity decline diminishes over time.

❖ Education, gender, and ethnicity factors appear to mediate the impact of T2DM on workplace efficiency. Efficiency losses are (other things equal) higher among males and ethnic minorities, while higher education appears to confer a degree of protection.

I incorporate these findings into the decision model by drawing upon the statistically significant parameter values in Table 3 in Lavigne et al. (2003), ignoring those pertaining to employment situation and the presence of other health conditions. These values were then used to predict expected work efficiency losses for decision-makers with varying combinations of personal characteristics and histories of T2DM management, by the number of years they had lived with T2DM. I consider four possible scenarios:

- After diagnosis, the individual chooses to manage their condition carefully through some combination of diet, LTPA, and medication adherence.

- After diagnosis, the individual chooses not to adhere, or to adhere only minimally to lifestyle modification and pharmacotherapy.

- After diagnosis, the individual initially (i.e., during the first decade) chooses to manage their T2DM carefully but allows management of their condition to lapse thereafter.

- After diagnosis, the individual initially (i.e., during the first decade) does not manage their condition well, but subsequently does so with greater vigilance.

Since Lavigne et al. (2003) did not investigate how the management of T2DM may influence the evolution of work efficiency losses, I assume the following:

- Health-related decisions affect productivity by influencing the rate of disease progression, including microvascular and macrovascular complications. As the literature did not furnish a useable estimate of the relationship between T2DM management and work productivity, I arbitrarily assume that proper management reduces the rate of accumulation of work efficiency losses to 50% of the level that would otherwise be observed, while poor management increases the rate of accumulation of efficiency losses by 50% of this value.

- Efficiency losses are assumed permanent, reflecting the progressive nature of T2DM and the irreversibility of at least some organ and tissue damage resulting from it. This has two implications:

    - After plateauing, work efficiency losses remain at this maximum level for the remainder of the individual's lifetime.[17]

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[17] To be clear, non-linearity of the annual increase in work efficiency losses is implied by the values of the parameters in Lavigne et al. (2003), which suggest that losses accumulate at a declining rate until ultimately reaching a peak. The assumption pertains to the evolution of work efficiency losses once the maximum is reached. From a purely mathematical perspective, the parameter values suggest losses should begin to diminish beyond this point, eventually culminating in negative losses. The latter is, however, implausible, and is assumed to primarily reflect the limitations of the estimation approach (e.g., lack of higher-order terms in the regression equation).

- There are limits to the extent to which someone who has previously managed their condition poorly can by modify their behaviour to prevent present and future productivity losses.

The prediction results are reported in Table 10:

Table 10: Work efficiency losses stemming from T2DM, by duration, education, gender, ethnicity, and disease management (hours per month)

Duration of T2DM (Years)	No college or graduate degree[1]								College or graduate degree[2]							
	Male				Female				Male				Female			
	WC/ WC[3]	PC/ PC[3]	WC/ PC[3]	PC/ WC[3]	WC/ WC[3]	PC/ PC[3]	WC/ PC[3]	PC/ WC[3]	WC/ WC[3]	PC/ PC[3]	WC/ PC[3]	PC/ WC[3]	WC/ WC[3]	PC/ PC[3]	WC /PC[3]	PC/ WC[3]
Caucasian ancestry																
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	5.4	7.6	5.4	7.6	0.9	3.1	0.9	3.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	5.8	9.0	5.8	9.0	1.3	4.5	1.3	4.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	6.0	10.3	6.0	10.3	1.5	5.8	1.5	5.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	6.2	11.6	6.2	11.6	1.7	7.1	1.7	7.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	6.3	12.8	6.3	12.8	1.8	8.3	1.8	8.3	0.0	0.9	0.0	0.9	0.0	0.0	0.0	0.0
10	6.3	17.5	7.9	17.2	1.8	13.0	3.4	12.7	0.0	5.6	1.6	5.4	0.0	1.1	1.6	0.9
15	6.3	20.2	14.6	18.5	1.8	15.7	10.1	14.0	0.0	8.3	8.3	6.7	0.0	3.8	4.6	2.2
20	6.3	20.9	19.3	18.5	1.8	16.4	14.8	14.0	0.0	9.1	9.1	6.7	0.0	4.6	4.6	2.2
25	6.3	20.9	20.9	18.5	1.8	16.4	16.4	14.0	0.0	9.1	9.1	6.7	0.0	4.6	4.6	2.2
Non-Caucasian ancestry																
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	16.9	19.1	16.9	19.1	12.4	14.6	12.4	14.6	5.0	7.2	5.0	7.2	0.5	2.7	0.5	2.7
2	17.2	20.5	17.2	20.5	12.7	16.0	12.7	16.0	5.4	8.6	5.4	8.6	0.9	4.1	0.9	4.1
3	17.5	21.8	17.5	21.8	13.0	17.3	13.0	17.3	5.6	10.0	5.6	10.0	1.1	5.5	1.1	5.5
4	17.7	23.1	17.7	23.1	13.2	18.6	13.2	18.6	5.8	11.2	5.8	11.2	1.3	6.7	1.3	6.7
5	17.8	24.3	17.8	24.3	13.3	19.8	13.3	19.8	5.9	12.4	5.9	12.4	1.4	7.9	1.4	7.9
10	17.8	29.0	19.4	28.7	13.3	24.5	14.9	24.2	5.9	17.1	7.5	16.8	1.4	12.6	3.0	12.3

Table 10: Work efficiency losses stemming from T2DM, by duration, education, gender, ethnicity, and disease management (hours per month)

Duration of T2DM (Years)	No college or graduate degree[1]								College or graduate degree[2]							
	Male				Female				Male				Female			
	WC/ WC[3]	PC/ PC[3]	WC/ PC[3]	PC/ WC[3]	WC/ WC[3]	PC/ PC[3]	WC/ PC[3]	PC/ WC[3]	WC/ WC[3]	PC/ PC[3]	WC/ PC[3]	PC/ WC[3]	WC/ WC[3]	PC/ PC[3]	WC /PC[3]	PC/ WC[3]
15	17.8	31.7	26.1	30.0	13.3	27.2	21.6	25.5	5.9	19.8	14.2	18.1	1.4	15.3	9.7	13.6
20	17.8	32.4	30.8	30.0	13.3	27.9	26.3	25.5	5.9	20.5	18.9	18.1	1.4	16.0	14.4	13.6
25	17.8	32.4	32.4	30.0	13.3	27.9	27.9	25.5	5.9	20.5	20.5	18.1	1.4	16.0	16.0	13.6

1 Includes “no certificate, diploma or degree” and “high school diploma or equivalent”.

2 Includes “Post-secondary certificate or diploma below bachelor level” and “university certificate, diploma, or degree at bachelor level or above”.

3 “WC/WC” (“well-controlled” → “well-controlled”) ≡ Similar to “Base”, but assumes work efficiency losses accumulate at half the rate estimated by Lavigne et al. (2003); “PC/PC” (“poorly-controlled” → “poorly-controlled”) ≡ Similar to “Base”, but assumes work efficiency losses accumulate at 1.5 times the rate estimated by Lavigne et al. (2003). “WC/PC” (“well-controlled”) ≡ Similar to “Base”, but assumes work efficiency losses accumulate at half the rate estimated by Lavigne et al. (2003); “WC/PC” (“well-controlled” → “poorly-controlled”) ≡ Initially similar to “WC/WC”, but beginning in the 11th year, work efficiency losses begin to accumulate at 1.5 times the base rate. “PC/WC” (“well-controlled” → “poorly-controlled”) ≡ Initially similar to “PC/PC”, but beginning in the 11th year, work efficiency losses fall to at 0.5 times the base rate.

Source: Author’s calculations, based on Lavigne et al. (2003)

Two key insights emerge from a review of the results in Table 10. First, work efficiency losses associated with T2DM accumulate more rapidly for men than women, for non-Caucasians than for Caucasians, and individuals with no college or graduate degree than for those with more education.

Second, most productivity losses are experienced in the first decade of illness—and, if the disease is consistently well-managed, within the first five years—excepting individuals who are less vigilant in managing their condition after previously having done so well (such patients do not avoid but may delay the accumulation of work efficiency losses). This implies that the benefits of improved self-management of T2DM among patients who initially did not manage their condition well are modest, which diminishes for such individuals the importance of sustaining workplace productivity as a rationale for modifying health-related behaviour.

Allocation of the burden of illness between workers and employers

LPT attributable to T2DM and its complications—that is, the sum of days absent from work and the hour-equivalent of health-reduced performance at work (Krol & Brouwer, 2014, p. 341; Stewart et al., 2003, p. 1236)—is likely not borne entirely by workers, but shared with employers and other members of society (e.g., impacts on other members of society through reduced government tax revenues). For the purposes of this research, it is assumed that a proportion of LPT is transferred to employers through paid sick days, and wage adjustments that do not fully reflect productivity decrements associated with chronic disease.

In Canada, there is generally no legal entitlement to paid sick days at either the federal or provincial level (Campaign for $15 and Fairness, 2015; Hesse, 2016; Levitt, 2017), although these may be extended to employees through collective agreements or workplace policies (Abedi, 2017). There appears to be wide variation across employers regarding provisions for paid sick leave, although recent Canadian data in this regard is scarce. While Statistics Canada (2015, 2017b) collects data on workplace absences attributable to illness or disability through the Labour Force Survey, it is unclear for what proportion of these absences employees are eligible to receive remuneration.

On the basis of findings from a Conference Board of Canada (2016) study of absence management in Canadian organizations, it appears reasonable to assume most workplaces offer less than two weeks of paid sick days for intermittent absences, and that the Canadian average is likely substantially lower than this. Acknowledging that this study does not account for workplaces that do not offer paid sick days and/or personal days, I assume that decision-makers who work full-time, irrespective of personal characteristics, are entitled to up to seven days of paid sick leave, while individuals who work part-time are entitled to receive remuneration for half this many (i.e., 3.5) days.[18]

Economic theory suggests that remuneration in the labour market is correlated with worker productivity (Ehrenberg & Smith, 2012, p. 65; Mankiw, 2006). However, there are a number of reasons this might not occur in practice (Dostie, 2011, p. 140), suggesting that wages may not always fully adjust in response to presenteeism stemming from chronic diseases, and that at least some proportion of work efficiency losses resulting from diabetes is transferred to employers. As the author could not identify existing estimates of the distribution of losses between workers and firms, it is assumed these are evenly divided among them (the same considerations referenced in Footnotes 18 also apply here).

Calculating total productive time lost to decision-makers

While the studies summarized above did not study how illness would affect people outside the workplace, it seems reasonable to suppose one can infer something about the total time a person spends ill (i.e., "sick days") and/or the

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18 Personal characteristics such as level of educational attainment, may affect access to paid sick leave through employer attributes. For example, individuals with lower levels of education might find themselves engaged in more precarious positions that offer fewer benefits, including paid sick days. Similarly, part-time and full-time positions may be qualitatively different in ways that have implications for the availability of paid sick leave.

time their overall functioning is affected by T2DM through observations on workplace absenteeism and presenteeism. The model therefore incorporates the following assumptions:

- ❖ Sick days may affect an individual at any time with equal probability. Absenteeism occurs when a person is unwell when they are expected to work, implying that the duration of illness a person experiences annually can be predicted from the number of workplace absences recorded during that same interval by dividing the latter (after conversion into hours) by the proportion of each year allocated to supplying labour.

- ❖ The magnitude of the productivity decrements experienced on the job due to T2DM is equivalent to those experienced outside the workplace. In addition, overall efficiency losses can be determined with reference to work efficiency losses by dividing the latter (after conversion into hours) by the proportion of each year allocated to supplying labour.

- ❖ Although in many workplaces there are opportunities to make up for time affected by illness, it is assumed that individuals cannot reallocate time originally set aside for leisure and engagement in health-promoting activities to compensate for the impact of absenteeism and presenteeism.

- For decision-makers who are unemployed or retired, all LPT is deducted from the time available for non-work activities.

The model further accounts for the transfer of productivity losses to employers by imposing the following assumptions:

- Individuals who are ill when scheduled to work can take advantage of paid sick days (the availability of which is assumed to depend on some combination of workplace policies, collective bargaining and/or legislation). Once they have exhausted their allotment of paid sick days, workers themselves incur the financial impacts associated with work absences.

- Individuals experiencing presenteeism can transfer half of the efficiency losses they incur to their employers (e.g., monitoring performance is costly, or contracts and/or legislation limit opportunities for wage adjustment).

- Workplace absences exceeding the available allotment of paid sick leave and work efficiency losses borne by workers cannot be diverted to non-work activities. Conceptually, an individual who is too sick to work is assumed to also be too ill to engage in LTPA or to enjoy other forms of leisure.

A diagrammatic representation of the approach outlined above is presented in Figure 4:

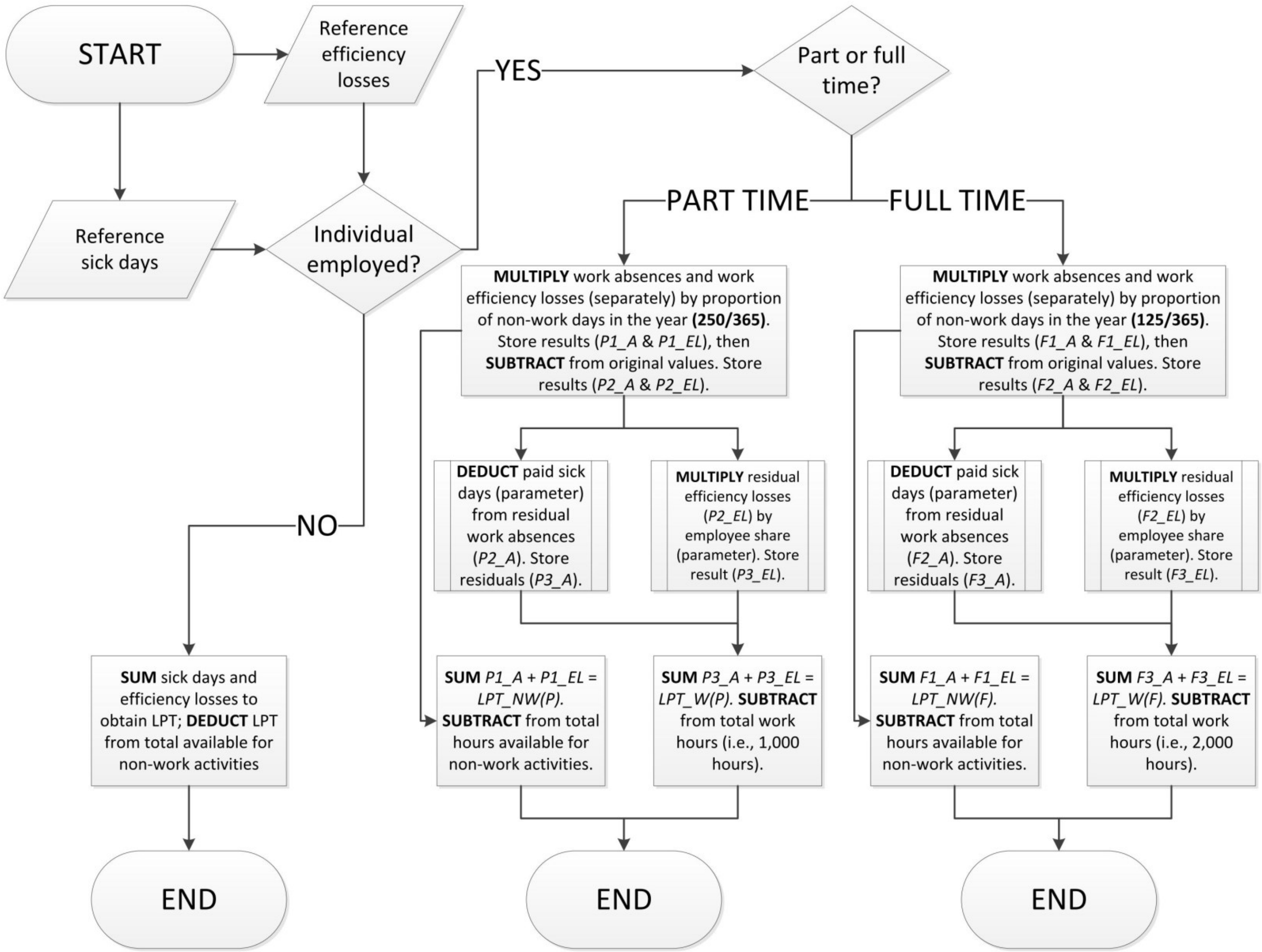
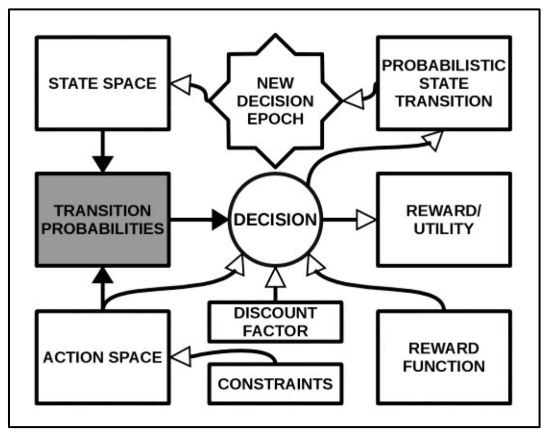


Figure 4: Diagrammatic representation of approach to calculating the impact of LPT on labour force participation and time available for non-work activities

Other impacts

Workers with T2DM may pay lower Pharmacare deductibles as their condition progresses, since workplace absenteeism and presenteeism will both reduce the level of household income against which the deductible rate is applied and could potentially push them into a lower income bracket characterized by a lower rate. This does not apply to people who are unemployed or retired, since their income does not depend on their state of health.

3.6 Transition probabilities



The core of the decision model is a matrix of transition probabilities that reflects the likelihood of transitioning from a given state in period T to another state in period T+1.

These probabilities may be driven by a range of factors, which include the decision-maker's fixed personal attributes (i.e., gender, ethnicity, and level of education attainment), the state they currently occupy (i.e., age, health and employment status, and, as applicable, the length of time elapsed since being diagnosed with T2DM and prior adherence to health-related behaviours), and the actions they take during specific decision epochs. In the case of health-related decision-making among individuals with T2DM, choices made during specific decision epochs (i.e., immediately following diagnosis, and again nine years later) are recorded through state assignment, enabling their consequences to carry forward into the future.

3.6.1 Normoglycemic/prediabetic → T2DM

Probabilities of transitioning from normoglycemia/prediabetes to T2DM are derived through application of the DPoRT 2.0 risk equations published by Rosella et al. (2014).

Overview of the DPoRT 2.0

The DPoRT is a Canadian population-based risk prediction tool for incident diabetes. The original version of the tool was developed from a cohort of 19,861 Ontario residents participating in Statistics Canada's 1996/97 National Population Health Survey whose information could be linked to health administrative databases (Rosella, Manuel, Burchill, & Stukel, 2011, p. 613). The current version of the tool (i.e., DPoRT 2.0) updates the risk equation coefficients with more recent data, including individuals from the original 1996 Ontario cohort and Ontario respondents of Cycle 1.1 (2001) and 2.1 (2003) of the CCHS linked to the

Ontario Diabetes Database, with follow-up until 2011 (Rosella et al., 2014, p. 18). It was externally validated in Ontario respondents using 2005 CCHS data linked to the Ontario Diabetes Database, with follow-up until 2011.

To ensure applicability across different populations, the variables considered for inclusion in the original study were those based on established evidence that would be easily and consistently captured using population surveys, and included age, height and weight, BMI, diagnosed chronic conditions (i.e., hypertension and heart disease), ethnicity, immigration status, smoking status, educational achievement, household income, alcohol consumption and physical activity (Rosella et al., 2011, p. 614). In deriving the risk equations, the authors subsequently excluded variables that did not improve their model or detracted from predictive accuracy, such as income, physical activity and alcohol consumption, and interacted age with BMI (i.e., to optimize goodness-of-fit and calibration) (p. 615). However, relative income (i.e., top income quintile) is subsequently incorporated into the DPoRT 2.0.

The authors ascertained that certain risk factors were important for one gender but not the other; for example, heart disease and smoking status was found to be a significant T2DM risk factor for men, but not women, while the reverse was true of immigration status (p. 615). They also determined that the best model fit was achieved by categorizing age differently for each gender.

Applying the DPoRT

The author developed a program that utilizes the DPoRT 2.0 risk equations to calculate the likelihood that previously-healthy (i.e., non-diabetic) individuals with a range of personal attributes (i.e., gender, age, ethnicity, educational attainment and relative income) and BMIs would develop T2DM over a one-year time-span. To preserve consistency with assumptions underlying the application of the UKPDS-OM2 (see Section 3.6.2 below), it was assumed individuals would not develop hypertension or heart disease prior to diagnosis with T2DM (although they might subsequently do so); are Canadian-born (i.e., did not immigrate here from elsewhere); and, do not smoke.

Tying health behaviours to BMI

The primary challenge associated with the application of the DPoRT 2.0 risk equations is the absence of an explicit link between health-related behaviours and the probability of T2DM. Recognizing that overweight and obesity constitutes a key risk factor for the development of T2DM (see Section 2.3.1 [page 33] in Chapter 2), this was achieved by modelling the impact of health-related decision-making on equilibrium body weight through its influence on the body's energy balance.

The first step involved defining adherence to healthy eating and LTPA in terms of caloric intake and expenditure. This is accomplished with reference to the categories of physical activity serving as the basis for equations developed by the Institute of Medicine to calculate the number of calories needed to maintain a stable weight, also known as an individual's estimated energy requirements (EERs) (Otten et al., 2006, p. 84):

- *Caloric expenditure.* I continue to employ the definition of LTPA presented in Section 2.3.1 (page 77), assuming that individuals who satisfy this would be classified as "active" according to the categorization scheme developed by the Institute of Medicine, while others would be classified as "sedentary".[19]

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19 150 minutes of weekly moderate-to-vigorous-intensity aerobic physical activity is about 21.4 minutes per day, which is clearly less than the lower end of the range for the low active category (i.e., 30-60 minutes of moderate activity per day). However, I assume that individuals' physical activities consist of some combination of moderate (i.e., $3 \leq \text{METs} < 6$) and vigorous (i.e., $\text{METs} > 6$) LTPA (Canadian Society for Exercise Physiology, 2017, pp. 11, 25), and that greater weight is attached to the latter, such that it contributes more than proportionally to achievement of the recommended target.

- *Caloric intake.* I assume a person who selects a high-quality or low-quality diet consumes a volume of calories consistent with the EERs for a person who is classified as "sedentary" or "active", respectively.[20]

I next adapt an approach utilized by Barton (2016) to calculate equilibrium body weight from information about individual caloric intake and energy expenditure. At the heart of this approach lies Equation (18), which indicates that an individual's weight in this period (i.e., W_t) is equal to their weight last period (i.e., W_{t-1}), plus any increment associated with the intake of calories from food and beverages (i.e., I_0), minus energy consumed through a combination of the thermic effect of feeding and physical activity, as well as of resting metabolism (i.e., E_{t-1}) (McArdle, Katch, & Katch, 2009, p. 193):[21]

(18) $$W_t = W_{t-1} + \frac{I_0}{7,716} - \frac{E_{t-1}}{7,716}$$

20 The model defines healthy eating habits with reference to the AHEI-2010, which is an index of dietary quality rather than quantity (caloric intake is not even a component of the AHEI scoring mechanism). Although it is possible to achieve higher AHEI scores without doing so, however, choosing to adhere to a high-quality diet does present opportunities for individuals to reduce their energy intake, for example by moderating their consumption of sugar-sweetened beverages, fruit juices, and alcohol. It does, however, indirectly influence the score, since the scoring components relating to trans fats and polyunsaturated fatty acids (PUFAs) evaluate consumption of each item in terms of its share of total caloric intake.

21 "7,716" refers to the number of calories found in a kilogram of body weight (Brusco, 2019).

Although Barton (2016) calculates energy expenditures using the Mifflin-St. Jeor equations, I instead utilize the equations developed by the Institute of Medicine for normal-weight (i.e., 18.5 kg/m^2 ≤ BMI < 25 kg/m^2) adult males and females (Otten et al., 2006, p. 82).[22] Operationalizing the equations requires estimates of individual height and weight. Information on height is gathered from observations on participants in the National Health and Nutrition Examination Survey, the results of which are summarized in the next section (see Table 12 below); I further assume that individuals initially have a BMI of just under 23 kg/m^2, enabling us to work backwards to derive their corresponding weight in kilograms.

As Barton (2016) observes, Equation (18) is an example of an affine discrete dynamical system (i.e., one in which the state at any moment is a function of its state at a previous point in time, where time is discrete, and a fixed constant is included), which means equilibrium body weight for males (W_M^*) and females (W_F^*) can be calculated as follows:

(19) $$W_M^* = \frac{\left[I_0 - 662 + 9.53 \times Age\right]}{PA_M \times 15.91} - \frac{539.6 \times Height}{15.91}$$

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22 Different equations have been compiled for other subsets of the population, including infants and young children, children and adolescents, women who are pregnant or lactating, and individuals with BMI ≥ 25 kg/m^2 (Garriguet, 2008, p. 3; Otten, Hellwig, & Meyers, 2006, p. 82).

(20) $$W_F^* = \frac{\left[I_0 - 354 + 6.91 \times Age\right]}{PA_F \times 9.36} - \frac{726 \times Height}{9.36}$$

Deriving the transition probabilities

Equilibrium BMIs can be readily derived from the equilibrium weights generated through the application of Equations (19) and (20). The former can then be inserted into the DPoRT 2.0 risk equations to predict the one-year probabilities of developing T2DM for individuals with varying characteristics (see Table 11).

Table 11: One-year probabilities (%) of developing T2DM, by gender, ethnicity, level of education, age, adherence to LTPA, and dietary quality

Age	Adheres to LTPA	Engages in healthy eating habits	No certificate, diploma or degree						High school diploma or equivalent						PS certificate or diploma (< bachelor level)						University certificate, diploma or degree (≥ bachelor level)					
			Afro-Caribbean		Asian-Indian		Caucasian		Afro-Caribbean		Asian-Indian		Caucasian		Afro-Caribbean		Asian-Indian		Caucasian		Afro-Caribbean		Asian-Indian		Caucasian	
			M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
25-34	Y	Y	0.8	0.7	0.8	0.7	0.4	0.4	0.8	0.7	0.8	0.7	0.4	0.4	0.6	0.5	0.6	0.5	0.3	0.3	0.6	0.5	0.6	0.5	0.3	0.3
	Y	N	0.8	0.7	0.8	0.7	0.4	0.4	0.8	0.7	0.8	0.7	0.4	0.4	0.6	0.5	0.6	0.5	0.3	0.3	0.6	0.5	0.6	0.5	0.3	0.3
	N	Y	0.8	0.7	0.8	0.7	0.4	0.4	0.8	0.7	0.8	0.7	0.4	0.4	0.6	0.5	0.6	0.5	0.3	0.3	0.6	0.5	0.6	0.5	0.3	0.3
	N	N	6.8	7.3	6.8	7.3	3.4	4.3	6.8	7.3	6.8	7.3	3.4	4.3	5.4	5.9	5.4	5.9	2.7	3.5	5.4	5.9	5.4	5.9	2.7	3.5
35-44	Y	Y	0.8	0.7	0.8	0.7	0.4	0.4	0.8	0.7	0.8	0.7	0.4	0.4	0.6	0.5	0.6	0.5	0.3	0.3	0.6	0.5	0.6	0.5	0.3	0.3
	Y	N	0.8	0.7	0.8	0.7	0.4	0.4	0.8	0.7	0.8	0.7	0.4	0.4	0.6	0.5	0.6	0.5	0.3	0.3	0.6	0.5	0.6	0.5	0.3	0.3
	N	Y	0.8	0.7	0.8	0.7	0.4	0.4	0.8	0.7	0.8	0.7	0.4	0.4	0.6	0.5	0.6	0.5	0.3	0.3	0.6	0.5	0.6	0.5	0.3	0.3
	N	N	6.8	7.3	6.8	7.3	3.4	4.3	6.8	7.3	6.8	7.3	3.4	4.3	5.4	5.9	5.4	5.9	2.7	3.5	5.4	5.9	5.4	5.9	2.7	3.5
45-54	Y	Y	4.4	1.5	4.4	1.5	2.2	0.9	4.4	1.5	4.4	1.5	2.2	0.9	3.5	1.2	3.5	1.2	1.7	0.7	3.0	1.2	3.0	1.2	1.5	0.7
	Y	N	4.4	1.5	4.4	1.5	2.2	0.9	4.4	1.5	4.4	1.5	2.2	0.9	3.5	1.2	3.5	1.2	1.7	0.7	3.0	1.2	3.0	1.2	1.5	0.7
	N	Y	4.4	1.5	4.4	1.5	2.2	0.9	4.4	1.5	4.4	1.5	2.2	0.9	3.5	1.2	3.5	1.2	1.7	0.7	3.0	1.2	3.0	1.2	1.5	0.7
	N	N	18.2	14.5	18.2	14.5	9.4	8.7	18.2	14.5	18.2	14.5	9.4	8.7	14.6	11.7	14.6	11.7	7.5	7.0	12.8	11.7	12.8	11.7	6.5	7.0

Table 11: One-year probabilities (%) of developing T2DM, by gender, ethnicity, level of education, age, adherence to LTPA, and dietary quality

Age	Adheres to LTPA	Engages in healthy eating habits	No certificate, diploma or degree						High school diploma or equivalent						PS certificate or diploma (< bachelor level)						University certificate, diploma or degree (≥ bachelor level)					
			Afro-Caribbean		Asian-Indian		Caucasian		Afro-Caribbean		Asian-Indian		Caucasian		Afro-Caribbean		Asian-Indian		Caucasian		Afro-Caribbean		Asian-Indian		Caucasian	
			M	**F**	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**
55-64	Y	Y	4.4	1.5	4.4	1.5	2.2	0.9	4.4	1.5	4.4	1.5	2.2	0.9	3.5	1.2	3.5	1.2	1.7	0.7	3.0	1.2	3.0	1.2	1.5	0.7
	Y	N	4.4	1.5	4.4	1.5	2.2	0.9	4.4	1.5	4.4	1.5	2.2	0.9	3.5	1.2	3.5	1.2	1.7	0.7	3.0	1.2	3.0	1.2	1.5	0.7
	N	Y	4.4	1.5	4.4	1.5	2.2	0.9	4.4	1.5	4.4	1.5	2.2	0.9	3.5	1.2	3.5	1.2	1.7	0.7	3.0	1.2	3.0	1.2	1.5	0.7
	N	N	18.2	14.5	18.2	14.5	9.4	8.7	18.2	14.5	18.2	14.5	9.4	8.7	14.6	11.7	14.6	11.7	7.5	7.0	12.8	11.7	12.8	11.7	6.5	7.0
65+	Y	Y	4.4	4.3	4.4	4.3	2.2	2.5	4.4	4.3	4.4	4.3	2.2	2.5	3.5	3.4	3.5	3.4	1.7	2.0	3.5	3.4	3.5	3.4	1.7	2.0
	Y	N	4.4	4.3	4.4	4.3	2.2	2.5	4.4	4.3	4.4	4.3	2.2	2.5	3.5	3.4	3.5	3.4	1.7	2.0	3.5	3.4	3.5	3.4	1.7	2.0
	N	Y	4.4	4.3	4.4	4.3	2.2	2.5	4.4	4.3	4.4	4.3	2.2	2.5	3.5	3.4	3.5	3.4	1.7	2.0	3.5	3.4	3.5	3.4	1.7	2.0
	N	N	18.2	14.2	18.2	14.2	9.4	8.6	18.2	14.2	18.2	14.2	9.4	8.6	14.6	11.5	14.6	11.5	7.5	6.9	14.6	11.5	14.6	11.5	7.5	6.9

Source: Author's calculations, based on DPoRT 2.0 risk equations (Rosella et al., 2014), Institute of Medicine equations for calculating estimated energy requirements (Otten et al., 2006), Barton's (2016) approach to calculation of equilibrium body weight, and miscellaneous other sources (Fryar, Gu, Ogden, & Flegal, 2016; Statistics Canada, 2014).

The results in Table 11 are largely consistent with expectations (e.g., men are at higher risk than women, individuals with Asian-Indian or Afro-Caribbean ancestry are at higher risk than individuals of Caucasian descent, and the likelihood of experiencing T2DM increases in middle-aged adults). Probabilities are the same for individuals of Afro-Caribbean and Asian-Indian descent because the DPoRT 2.0 Risk Equations distinguish only between Caucasians and those of "non-white ethnicity" (Rosella et al., 2014, p. 21).

It should be noted that the three ethnic categories in the table were selected to preserve consistency with the UKPDS-OM2, which includes only these groups (University of Oxford Diabetes Trials Unit & Health Economics Research Centre, 2015, p. 2).

3.6.2 T2DM ↔ T2DM

As discussed in Section 3.6.1, the DPoRT risk equations were developed to calculate the risk of transitioning from normoglycemia/prediabetes to T2DM; however, the DPoRT was designed to consider neither the progression of T2DM itself (i.e., the emergence of microvascular and macrovascular complications) nor the likelihood of mortality in those who have been diagnosed. A review of the literature concluded that the UKPDS-OM2 could address this gap.

Overview of the UKPDS-OM2

Licensed through the University of Oxford (University of Oxford Diabetes Trials Unit & Health Economics Research Centre, 2015), the UKPDS-OM2 is a spreadsheet application implemented in MS Excel which draws upon data from the 30-year UKPDS to predict lifetime health outcomes and health care costs associated with actual or hypothetical T2DM intervention costs, for cohorts consisting of real or simulated T2DM patients.

One attractive feature of the UKPDS-OM2 is that it is equipped to calculate the probability of significant clinical events using a series of validated risk equations that draw upon 89,760 patient-years of data collected from 5,102 participants in the UKPDS (Hayes et al., 2013a, p. 1925), which is among the largest and most influential studies ever conducted with T2DM patients (American Diabetes Association, 2002; "UKPDS: United Kingdom Prospective Diabetes Study," 2017). In addition, while the model comes pre-packaged with a set of default values derived from the literature for parameters that drive the calculation of HRQoL and health care expenditures, it is also highly customizable, enabling users to insert values more suitable to the context to which their research applies.

Designation of values for model parameters

While the UKPDS-OM2 can in principle be used to assess the likelihood of experiencing a wide variety of microvascular and macrovascular complications, this information could be applied only by incorporating an enormous number of additional health states into the individual decision model, which, in turn, would render it difficult or impossible to tabulate optimal policies.

It was therefore decided to conceptualize T2DM progression in terms of patients' ages and time elapsed since diagnosis. For every possible combination of gender, ethnicity, and age at diagnosis and each possible configuration of patient behaviours (reflected in the values of five key risk factors discussed below) Monte Carlo simulations were carried out using the UKPDS-OM2 to derive annual probabilities of all-cause mortality and HRQoL. These figures implicitly account for the accumulation of diabetic complications and their impact upon patient survival and well-being.

The first step in choosing parameter values for the UKPDS-OM2 involved constructing a hypothetical starting cohort with prespecified characteristics (i.e., gender, age and ethnicity, duration of T2DM, height and weight) and initial risk factor values that one might reasonably expect to observe (i.e., that are clinically plausible) in patients just diagnosed with T2DM. I made the following assumptions to ensure tractability of the model given constraints on available computing resources:

- *Rapid diagnosis of T2DM in primary care settings.* I assume there is no lag between the emergence of T2DM and its diagnosis by family physicians. The implies that the duration of T2DM for all newly diagnosed patients is zero, and that said patients have not yet begun to experience diabetic complications or discrete risk factors for diabetic progression. This was done primarily to avoid modelling differences in health outcomes attributable to variability in access to and quality of primary care, which lies outside the scope of this research.

- *Exclusion of socio-economic factors.* It is assumed that socio-economic factors do not influence variability across patients initially presenting with T2DM. This is because the decision model already partially accounts for the influence of these factors through an individual's income, which is strongly correlated with (though not necessarily determined by) their level of educational attainment.

- *Patients are non-smokers.* The addictive quality of smoking, which distinguishes it from many other health-related decisions, would be difficult to integrate into the decision model, because it would require the model to keep track of the stock of the addictive commodity maintained by the individual at each point in time.

Table 12 presents values for the characteristics of the starting cohort of those newly diagnosed with T2DM, subject to the assumptions described above:

Table 12: Characteristics of the UKPDS—OM2 starting cohort of newly diagnosed T2DM cases						
	Ethnicity: Caucasian		**Ethnicity: Afro-Caribbean**		**Ethnicity: Asian-Indian**	
	Male	**Female**	**Male**	**Female**	**Male**	**Female**
Demographic characteristics						
Weight (kg)	94.093	79.609	80.904	69.079	71.055	60.390
Height (m)	1.771	1.629	1.764	1.630	1.703	1.570
BMI (kg/m^2)	30		26		24.5	
Risk factors (discrete)						
Atrial fibrillation; peripheral vascular disease; current smoker; albuminuria	N	N	N	N	N	N
Risk factors (continuous)						
HDL cholesterol (mmol/l)	1.30	1.30	1.30	1.30	1.30	1.30
LDL cholesterol (mmol/l)	4.40	4.40	4.40	4.40	4.40	4.40
Systolic blood pressure (SBP) (mmHg)	140	140	140	140	140	140
HbA_{1c} (%)	7.0	7.0	7.0	7.0	7.0	7.0
Heart rate (bpm)	73	75	73	75	73	75
White blood cell count (x10^9/l)[1]	7.2	7.2	7.2	7.2	7.2	7.2
Haemoglobin (g/dl)	16.0	14.0	16.0	14.0	16.0	14.0
Estimated glomerular filtration rate (eGFR) (ml/min/1.73 m^2)	Age-dependent	Age-dependent	Age-dependent	Age-dependent	Age-dependent	Age-dependent
Derived from: Canadian Blood Services (2017); Canadian Diabetes Association Clinical Practice Guidelines Expert Committee (2013); Chiu et al. (2011); Foos, McEwan, and Grant (2014); Fryar et al. (2016, pp. 13, 15); Hillis et al. (2012); Tong et al. (2004)						

The second step in the process involved determining how each combination of health-related behaviours influences the evolution of five key risk factors incorporated into the UKPDS-OM2, including HbA1c, SBP, weight, and low- and high-density lipoprotein cholesterol (LDL-C and HDL-C, respectively). This step was guided by the following key assumptions:

- If patients do not adhere to any of the health-related behaviours just mentioned, risk factors evolve according to the prediction formulas packaged with the model and the initial values for the cohort presented in Table 12 (excepting smoking status, which was fixed at its initial value).

- Excepting body weight, the evolution of which is simulated using the same approach used Section 3.6.1, the effects of adherence upon each health-related behaviour are additive, and they influence progression of T2DM by generating deviations from model-predicted risk factor values, thereby reducing the likelihood of experiencing complications.

- Health-related behaviors are defined in the same manner described in Section 2.3. However,

- *Dietary intake.* This research assesses the quality of dietary intake (i.e., in relation to chronic disease risk) through the application of the AHEI-2010 dietary index. However, since few studies undertaken to date have examined the relationship between AHEI scores and the risk of experiencing microvascular and macrovascular complications among individuals with T2DM (Huffman, Zarini, Mcnamara, & Nagarajan, 2011; Wu, Huang, Lei, & Yang, 2016), it is assumed that the benefits of healthy eating for individuals with T2DM can be approximated by the gains associated with the receipt of medical nutrition therapy (i.e., treatment of a medical condition through modifications to diet) ("Nutrition therapy," 2017), the implicit assumption being that adherence to such therapy could reasonably be expected to generate high AHEI scores. On the basis of a recent systematic review undertaken by Franz et al. (2017) examining the effectiveness of medical nutrition therapy delivered by Registered Dietitian Nutritionists, I assume that full adherence to diets with high AHEI-2010 scores can generate 1.25% reductions in HbA_{1c} and 6.1 mm Hg reductions in SBP, but not meaningful reductions in LDL-C or significant increases in HDL-C. I maintain consistency with the approach employed in Section 3.6.1 by assuming that adherence and non-adherence to healthy eating habits is synonymous with levels of caloric intake that would facilitate achievement of a BMI of 23 kg/m^2 for sedentary and active individuals, respectively.

Adherence to physical activity is defined in terms of time engaged in moderate-to-vigorous-intensity aerobic exercise outside the workplace. Numerous studies have examined how aerobic exercise affects the risk factors included in this process (Avery, Flynn, van Wersch, Sniehotta, & Trenell, 2012; Figueira et al., 2014; Hayashino, Jackson, Fukumori, Nakamura, & Fukuhara, 2012). On the basis of these studies, it is assumed that full adherence to *Canadian Physical Activity Guidelines* with respect to participation in aerobic exercise (150 minutes per week) generates reductions in HbA1c and SBP of 0.46% and 4.57 mm Hg, respectively, but that LTPA participation of this nature does not produce meaningful reductions in LDL-C or significant increases in HDL-C. I again seek to preserve consistency with Section 3.6.1 by assuming that adherence and non-adherence to LTPA is synonymous with levels of caloric expenditure for active and sedentary individuals, respectively, as defined in Otten et al. (2006, p. 82).

For the purposes of this research medication adherence is defined in terms of the proportion of each 365-day period for which a patient with T2DM maintains a supply of medication (see Section 2.3.3 above). To provide context for this activity, I conferred with a practicing local pharmacist to compile a list of medications and medical supplies patients with T2DM commonly use at varying stages of disease progression, including typical daily dosages. The results of this activity are presented in Section 3.5.1 and Appendix C. Several studies have examined the relationship between medication adherence and glycemic control (Asche et al., 2011; Egede et al., 2014; Nerat, Locatelli, & Kos, 2016; Pladevall et al., 2004; Schectman et al., 2002). In addition, two Cochrane Reviews have examined the effectiveness of antihypertensive and lipid-lowering medications (Adams, Sekhon, & Wright, 2014; Heran, Wong, Heran, & Wright, 2008).

Table 13 summarizes the results of the literature review for all risk factors aside from BMI:

Table 13: Summary of impact of adherence on HbA1c, SBP, HDL-C and LDL-C

Lifestyle behaviour			Cumulative impact of T2DM risk factors			
LTPA	**Dietary quality**	**Medication adherence**	**HbA1c (%)**	**SBP (mm Hg)**	**HDL-C (mmol/L)**	**LDL-C (mmol/L)**
No	No	No	0.00	0.00	0.0%	0.0%
Yes	No	No	-0.46	-4.57	0.0%	0.0%
No	Yes	No	-1.25	-6.10	0.0%	0.0%
No	No	Yes	-1.50	-6.29	7.3%	-49.9%
Yes	Yes	No	-1.71	-10.67	0.0%	0.0%
Yes	No	Yes	-1.96	-10.86	7.3%	-49.9%
No	Yes	Yes	-2.75	-12.39	7.3%	-49.9%
Yes	Yes	Yes	-3.21	-16.96	7.3%	-49.9%

Synthesized from: Franz et al. (2017); Avery et al. (2012); Figueira et al. (2014); Hayashino et al. (2012); Asche et al. (2011); Egede et al. (2014); Nerat et al. (2016); Pladevall et al. (2004); Schectman et al. (2002); Adams et al. (2014); Heran et al. (2008)

Table 14 summarizes the impact of various combinations of health-related behaviour on BMI; it should be noted that medication adherence does not appear in the table, as the literature reviewed did not indicate a strong relationship between body weight and compliance with pharmacotherapy:

Table 14: Predicted BMI (kg/m^2) for individuals with varying combinations of health-related behaviours, by gender and ethnicity							
Lifestyle behaviour		**Ethnicity: Caucasian**		**Ethnicity: Afro-Caribbean**		**Ethnicity: Asian-Indian**	
LTPA	**Dietary quality**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**
No	No	33.54	42.07	33.56	42.06	33.73	42.55
Yes	No	23.00	23.00	23.00	23.00	23.00	23.00
No	Yes	23.00	23.00	23.00	23.00	23.00	23.00
Yes	Yes	<18.5	<18.5	<18.5	<18.5	<18.5	<18.5

NOTE: People with BMIs lower than 18.5 kg/m^2 are typically classified as underweight (US CDC, 2015).
Source: Author's calculations, derived from sources and methodology outlined in Section 3.6.1 (page 156)

The next step was to populate the UKPDS-OM2 input workbooks, establish simulation settings, and run the model. Given the large number of scenarios to be considered, it was necessary to automate the preparation of the input workbooks, which was achieved by creating a template incorporating a macro developed by the author in Visual Basic for Applications. Details regarding the template and the settings established by the macro are presented in Appendix D.

Processing and application of simulation results

Two key pieces of information were extracted from the simulation output, namely all-cause mortality event rates and quality-adjusted life expectancy. This was then incorporated into the decision model by converting all-cause mortality event rates (i.e., the proportion of the original cohort who die each period) into transition probabilities (i.e., the proportion of patients alive at the end of the previous period who die during this period), and quality-adjusted life expectancy (i.e., a composite measure reflecting the number of years someone can expect to live in full health) into average HRQoL. In both cases, this was accomplished by dividing the values of interest by the proportion of the cohort surviving to each year.

3.6.3 Other health state transition probabilities

The last required health state transition probabilities are mortality rates for individuals who are normoglycemic or prediabetic; these are derived from the 2014-2016 life tables for Manitoba (Statistics Canada, 2018a).

3.6.4 Approach to modelling employment state transitions

This section expands on Section 3.2.2 by describing how labour force participation is incorporated into the decision model and under what circumstances people may transition between employment states. It concludes by presenting the baseline transition probabilities incorporated into the model, which are derived from data from the 2011 SLID PUMF.

Overview of the approach and key assumptions

The following assumptions underpin modelling of employment state transitions:

- The decision model categorizes all individuals as either employed or unemployed. This classification scheme is driven purely by the desire to limit the number of model states, and the implied definition of unemployment—which includes literally everyone who is not employed—does not align with the more familiar conceptualization of unemployment (Statistics Canada, 2018b, p. 6). To bridge this gap, we can think of the unemployed as being of two distinct types:

- Out-of-work labour force participants attempt to recover employment by engaging in search, and, indeed, are required to do so as a condition of participation in the EIA Program (see page 131 in Section 3.5.1).

- Since active labour force participation is effectively mandatory for those not positioned to retire, non-participants consist exclusively of retirees.

- Individuals younger than 65 remain employed unless involuntarily separated from their position. There is no motivation to leave a job unless retiring, since there is no prospect of obtaining better-remunerated work through search.

- Employment state transition probabilities are correlated with an individual's gender, age, and level of educational attainment, but not their current choices, excepting the decision to retire (see below).

- Individuals aged 65 or older retire in one of two ways:

- As noted in Section 3.3.1 above, a subset of the action space is specifically dedicated to retirement. By selecting one of these actions, a person voluntarily withdraws from the labour force by modifying the probabilities that govern transitions between employment states to ensure they occupy the unemployed state in the subsequent period. As a reward for this decision, the individual begins earning retirement income immediately.[23]

- Decision-makers who are unemployed at age 65 or who subsequently lose their job in any given decision epoch are effectively forced out of the labour market; this is accomplished by modifying the employment state transition probabilities so that the likelihood of recovering employment is equal to zero. People who experience retirement in this way receive employment income in the period in which job loss occurs, and retirement income thereafter (see footnote 11 on page 118).

- However it occurs, retirement is assumed permanent, in that people exiting the labour force cannot subsequently rejoin it.

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[23] Excepting instances in which the individual retires, the transition to unemployment is assumed to occur at the end of the current period—after the individual has earned their reward (or within-period utility) for the decision epoch under consideration. Retirees are technically classified as employed in the period the decision to retire is taken, but because their reward depends on the choice they make as well as on their current state, the program overrides the latter, enabling decision-makers to receive CPP, OAS and GIS benefits immediately.

Rationale for the selected approach to modelling work cessation

The discussion in the preceding sub-section indicates that, with two notable exceptions (i.e., job destruction experienced after reaching the standard age of retirement, or mortality), work cessation in the model is the outcome of calculated decision-making on the individual's behalf. For this reason, it is important to consider what factors might motivate the retirement decision:

- *Declining productivity and wages.* One economic explanation for why people retire is that productivity begins to decline beyond a certain age, reflecting depreciation of human capital (Mincer, 1974), due, for example, to obsolescence of knowledge or skills, or to deterioration in physical and mental faculties accompanying age or attributable to declining health (Blundell, French, & Tetlow, 2016, p. 488; Laitner & Sonnega, 2012; Mortelmans & Vannieuwenhuyze, 2013, p. 13). This may make work cessation more attractive, particularly if other sources of income exist. There is mixed evidence regarding the significance of declining productivity and wages as an explanation for the retirement decision (Blundell et al., 2016, p. 488).

- *Alternative sources of income and/or benefits.* The timing of retirement may also be affected by the availability of non-wage income, such as public and private pensions, Registered Retirement Savings Plans, Tax-Free Savings

Accounts, financial investments (e.g., stocks and bonds), personal savings accounts, annuities, and home equity (Financial Consumer Agency of Canada, 2017). Incentives generated by private and public pensions, other government programs and, in some contexts, the accessibility of health insurance can affect behaviours in at least three ways (Blundell et al., 2016):

- High implicit tax rates on labour income beyond a certain age can motivate older workers to substitute leisure for work, especially if combined with declining workforce productivity.

- Pension systems typically involve some degree of redistribution, increasing or decreasing lifetime income. This is turn can affect the length of time people must work to finance retirement.

- If people respond to the availability of the public pension by reducing private savings, it may influence when they can retire.

- *The opportunity cost of time.* Retirement enables people to reallocate time to other activities, such as leisure, receipt of medical care, and/or provision of informal care for family members (Blundell et al., 2016, pp. 541–542; McGeary, 2009, p. 310; Mortelmans & Vannieuwenhuyze, 2013, p. 13). When productivity declines, so too does the opportunity cost of engaging in non-work activities, which should motivate the household to substitute these for labour (Laitner & Sonnega, 2012, p. 14)—though only to a degree, since leisure and consumption are complements in the production of utility. Also, because the utility function is characterized by negative state dependence, declining health may reduce the enjoyment people derive from leisure.

Baseline transition probabilities

Selection of values or ranges for parameters incorporated into the decision model is undertaken using data from the PUMF for the 2011 SLID Person File—the most recent available, as the SLID was discontinued in mid-2012 (Corak, 2012). The value of the SLID in the current context lies in the collection of monthly data regarding respondents' participation in the labour force, which is applied here to calculate the annual probability of transitions to employment and unemployment for people with specific combinations of individual characteristics and differing levels of educational attainment.

Because there are too few observations from each jurisdiction to study how transition probabilities vary by gender, age category, and level of education, this analysis does not discriminate according to place of residence, but rather takes advantage of all cases in the PUMF, except individuals younger than 25, individuals unable to report their level of educational attainment, and individuals whose labour force status was recorded as “not applicable” or who were out of the labour force in January 2011 (because the decision model conceptualizes labour force withdrawal as largely discretionary).

The SLID 2011 PUMF does not include an observation for December 2011. As such, there are only eleven months’ worth of transition probabilities. I rectify this by assuming that the state transition probabilities applying to the interval between December 2011 and January 2012 are equivalent to those applying to the preceding month. Simple matrix algebra then enables me to derive estimates of the likelihood that individuals who are either employed or unemployed at the start of the 12-month period will occupy either one of those states one year later (where the labels adjoining the left-hand side and top of each matrix below indicate the initial and final state under consideration, while the subscripts and superscripts denote the month and year of the observation, respectively):

$$\begin{array}{c|cc|} & \boldsymbol{E_D^{11}} & \boldsymbol{U_D^{11}} \\ \hline \boldsymbol{E_J^{11}} & p_e^e & p_e^u \\ \boldsymbol{U_J^{11}} & p_u^e & p_u^u \\ \hline \end{array} \times \begin{array}{c|cc|} & \boldsymbol{E_J^{12}} & \boldsymbol{U_J^{12}} \\ \hline \boldsymbol{E_D^{11}} & p_e^e & p_e^u \\ \boldsymbol{U_D^{11}} & p_u^e & p_u^u \\ \hline \end{array} = \begin{array}{c|cc|} & \boldsymbol{E_J^{12}} & \boldsymbol{U_J^{12}} \\ \hline \boldsymbol{E_J^{11}} & p_e^e & p_e^u \\ \boldsymbol{U_J^{11}} & p_u^e & p_u^u \\ \hline \end{array}$$

The annual employment state transition probabilities incorporated into the decision model are presented in Table 15 below:

Table 15: Estimated annual employment state transition probabilities						
Recorded labour force status, January 2011			**Projected labour force status, January 2012**			
			Did not receive a certificate from a university or other post-secondary institution[1]		**Receive a certificate from a university or other post-secondary institution[2]**	
			Employed	**Unemployed**	**Employed**	**Unemployed**
Male	**Age 25-55**	**Employed**	96.9%	3.1%	97.7%	2.3%
		Unemployed	51.3%	48.7%	59.8%	40.2%
	Age 55+[3]	**Employed**	97.0%	3.0%	96.0%	4.0%
		Unemployed	34.7%	65.3%	42.8%	57.2%
Female	**Age 25-55**	**Employed**	97.5%	2.5%	98.2%	1.8%
		Unemployed	54.1%	45.9%	64.0%	36.0%
	Age 55+[3]	**Employed**	97.5%	2.5%	98.2%	1.8%
		Unemployed	29.5%	70.5%	53.3%	46.7%

1 Includes individuals who did not attend school, attended but did not complete primary or secondary school, and those who completed high school and/or attended university or non-university post-secondary institution (e.g., community college, business school, trade or vocational school, or collège d'enseignement général et professionnel) but did not receive a certificate.

2 Includes individuals who reported having a non-university certificate, a university certificate below a Bachelor's degree, and/or a Bachelor's degree or higher level of university certificate, including professional degrees in law, medicine, dentistry, veterinary medicine or optometry.

3 Information on labour force status was only collected for individuals between the ages of 16-69.

Source: Income Statistics Division, Statistics Canada (2011, 2014, 2015)

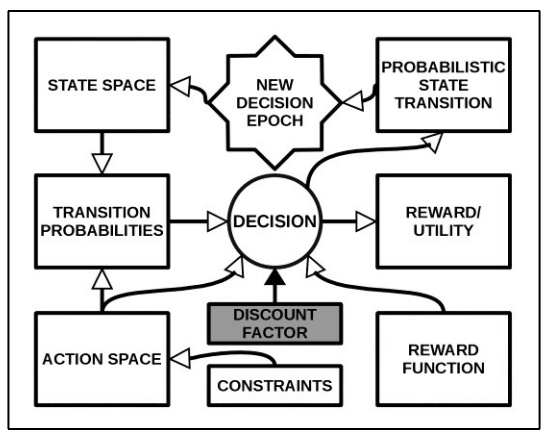
Impact of T2DM on the probability of employment state transitions

Employer discrimination could conceivably place diabetics at higher risk of being terminated from their position and may reduce their chances of recovering employment (Tunceli et al., 2005, p. 2662; Von Korff et al., 2005, p. 1326). However, findings presented in Chapter 2 suggest that although T2DM is associated with a lower probability of being employed, it is not clearly associated with a higher probability of being *unemployed*, which could imply that much of the difference in employment rates reflects the individual's decision to withdraw from the labour force. As such, the model assumes that T2DM and its complications do not affect the likelihood of employment state transitions.

Impact of T2DM on work cessation

The literature summarized in Chapter 2 suggests T2DM may significantly accelerate labour force exit. As noted in Section 3.6.4 (page 176), however, the decision model does not impose retirement on decision-makers, but rather regards retirement as a deliberate response to factors such as declining workplace productivity and eligibility for public pensions. This discussion implies that the impact of T2DM upon work cessation acts through a collection of parameters that, in turn, influence the individual's decision-making calculus.

3.7 Discount factor



Discounting future costs and benefits reflects the notion that it is preferable to enjoy benefits now while defraying costs into the future (Drummond, Sculpher, Claxton, Stoddart, & Torrance, 2015, p. 241). For example, it is preferable to receive one dollar today than the same dollar one year from now, since an individual then has the option of consuming that income immediately or investing it and enjoying higher levels of consumption later.[24] As in other intertemporal optimization problems, the framework imposes the assumption that individuals discount future benefits and costs at a constant rate (i.e., it incorporates exponential discounting); the extent to which people favour a unit of consumption in the present over the future is embodied in the value of the discount factor δ, which falls in the closed interval [0, 1]. By default, the model assumes a discount factor of 0.95. However, the sensitivity analysis considers several other possible values for this parameter, including 1.00, 0.75, 0.50 and 0.

4. MODEL SOLUTION

This chapter has so far focused upon identifying the central components of the model and selecting suitable values (or ranges of values) for its parameters. I now turn to demonstrating how the model combines these components and, finally, the model's solution.

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24 Other reasons for a positive rate of time preference include the presence of risk ("a bird in the hand is worth two in the bush"), optimism about future economic prospects (which would reduce the marginal utility of wealth in the future, making consumption more attractive now), and the ability to generally earn a positive return when making a riskless investment (Drummond, Sculpher, Claxton, Stoddart, & Torrance, 2015, p. 241; Paulden, 2014, p. 396).

4.1 Theoretical synthesis: production of health as the modification of a stochastic process:

This research follows Zweifel, Breyer, and Kifmann (2009) in conceptualizing health investment as a conscious effort to increase the likelihood of occupying desirable health states while reducing the likelihood of experiencing undesirable ones. As noted in Section 3.2 in Chapter 2 above (page 51), this approach deviates significantly from earlier models of health investment in highlighting the unpredictability of health outcomes and the limited control patients exercise over health state transitions.

I present here a simplified version of the decision model that preserves many of its fundamental features. Before proceeding, I caution that the results presented here are primarily illustrative, since the discrete nature of the decision model's state and action spaces implies it is not amenable to solution through application analytical techniques—a point to which I return in Section 4.2.3 below. The simplified model has the following characteristics:

- An individual seeks to maximize lifetime well-being by allocating their resources to consumption (c_t) and leisure (ℓ_t), which directly generate utility, and to two generic health-promoting behaviours (d_t and e_t), which do not. All income is derived from labour (L_t), which is remunerated at rate $\overline{w}$. In addition, Ω is total time available to the individual, while p and T refer, respectively, to the amounts of income and time he or she must forgo to acquire an additional unit of some good (where the superscript identifies what that good is). Finally, $LPT_t(h_t)$ denotes lost productive time, which is tied to the individual's state of health (i.e., h_t).

- Adherence to health-promoting behaviours is "sold" in infinitely divisible units that require outlays of income and time. The decision-maker's full-income constraint is as follows:

(21) $$\overline{w}\Omega = \overline{w}\left[\ell \qquad -T^d d_t + LPT_t\left(h_t\right)\right] + p^c c_t + p^e e_t + p^d d_t$$

- Preferences over consumption and leisure are given by Equation (14).

- The individual lives for two periods, "today" (t = 0) and "tomorrow" (t = 1), and then dies. He or she is healthy today but falls ill tomorrow with probability $p(d_0, e_0)$. As this notation implies, the decision-maker can influence the risk of experiencing illness by investing time and income in the two activities referenced above. I simply assume that increased investment in either activity reduces the risk of disease.[25]

$$\frac{\partial p(e_t, d_t)}{\partial e_t} < 0; \qquad \frac{\partial p(e_t, d_t)}{\partial d_t} < 0$$

- The individual is motivated to avoid illness for two reasons. First, sickness directly impacts quality of life, as reflected by the term $f(h_t)$ in Equation (14). Second, illness results in lost productive time that becomes unavailable for other activities.

With reference to the discussion in Section 3.3 in Chapter 2 (page 56), the Bellman Equation for this simple two-period dynamic stochastic optimization problem is as follows:

(22)

$$\begin{aligned} V_0(h_0 = H) &= \max_{c_0, \ell} \left\{ u_0\big(f(h_0 = H), c_0, \ell \qquad V_1(h_1)\big]\right\} \\ &= \max_{c_0, \ell} \left\{ u_0\big(f(h_0 = H), c_0, \ell \qquad \begin{bmatrix} p(e_0, d_0) \times V_1(h_1 = S) + \\ (1 - p(e_0, d_0)) \times V_1(h_1 = H) \end{bmatrix} \right] \right\} \end{aligned}$$

[25] For example, I set aside the questions of whether the effectiveness of a certain activity in reducing risk increases or decreases with participation in that activity or other activities they may undertake.

As with the decision model, I solve the problem presented in Equation (22) by considering the states the individual may occupy in the second and final period, and then working backwards to the present (i.e., backward induction). I begin by noting that the individual has no incentive to invest in health beyond the first period of life, since there is no third period during which they would experience any consequences from underinvestment. Recognizing this, the maximum level of utility achievable from the second period sub-problem is as follows:

$$V_1\left(h_1 = S\right) = \underbrace{f\left(h_1 = S\right)}_{\text{Equal to 1 if healthy}} \times \frac{\Omega - \overbrace{LPT_1\left(h_1 = S\right)}}{\left[\alpha^{\frac{1}{\rho-1}} w^{\frac{\rho}{\rho-1}} + \left(1-\alpha\right)^{\frac{1}{\rho-1}} p_c^{\frac{\rho}{\rho-1}}\right]} \times \tag{23}$$

$$= \left[\alpha\left(\frac{\bar{w}}{p^c}\right)^{\rho} \times \left[\left(1-\alpha\right)^{\frac{1}{\rho-1}} p_c^{\frac{\rho}{\rho-1}}\right]^{\rho} + \left(1-\alpha\right) \times \left[\alpha^{\frac{1}{\rho-1}} \bar{w}^{\frac{\rho}{\rho-1}}\right]^{\rho}\right]^{\frac{1}{\rho}}$$

Three points bear mentioning at this juncture:

- ❖ Equation (23) is derived from the solution to the second period sub-problem for individuals who transition to illness after having previously been healthy. The analogous result for people who sustain their health in the second period is obtained by setting $f(h_1) = 1$ and $LPT(h_1) = 0$, since healthy people experience neither HRQoL decrements nor LPT.

- ❖ Provided $f(h_1 = S) < 1$ and $LPT(h_1 = S) > 0$ (true by assumption), one can readily demonstrate that $V(h_1 = H) > V(h_1 = S)$.

- ❖ As Adda and Cooper (2003) point out, indirect utility functions derived through the solution to static optimization problems are analogous to value functions derived from solving dynamic optimization problems (pg. 12).

I now return to the original problem, which is simpler because the decision-maker has articulated what they must do in the second period to maximize their well-being, irrespective of the state of health they ultimately encounter. I do not attempt to solve the problem outlined in Equation (22), which, in practice, is difficult or impossible unless one selects a functional form for $p(e, d)$; however, examining the first order conditions the solution must satisfy furnishes valuable insights that may help in understanding results derived from the decision model:

(24) $\frac{(1-\alpha)^{\rho}\ell}{\overline{w}} \qquad \frac{{}_{0}^{,\rho-1}}{p^{c}}$; (25) $\frac{\partial p(e_0, d_0)/\partial d_0}{p^{d} + \overline{w}T^{d}} = \frac{\partial p(e_0, d_0)/\partial e_0}{p^{e} + \overline{w}T^{e}}$

Equation (24) is a standard result indicating that the individual maximizes their well-being by allocating their resources such that at the margin, consumption and leisure should yield the same level of marginal utility per dollar spent on each. Analogously, Equation (25) directs the individual to invest in health in such a way as to equalize the level of risk reduction achieved with the last dollar allocated to each type of health-promoting activity, where health expenses are understood to include both financial outlays and the value of their time.

Equation (26) (below) states that the individual has made the best possible use of their scarce resources when the additional utility achievable by spending a dollar on consumption is equal to the present value of the expected gain in future welfare that results from reducing the likelihood of illness:[26]

$$(26) \quad \frac{\alpha^{\rho} c_{0}^{\rho-1}\left[\alpha c_{0}^{\rho}+(1-\alpha)\ell\right.}{p^{c}}^{\;1-\rho} - \frac{\cdot\left[\partial p\left(e_{0}, d_{0}\right)/\partial e_{0}\right]\left[V_{1}\left(h_{1}=H\right)-V_{1}\left(h_{1}=S\right)\right]}{p^{e}+\overline{w}T^{e}}$$

Equation (26) goes to the heart of the decision problem, saying, in effect, that a rational decision-maker will weigh the immediate costs involved in investing in health (i.e., reduced opportunities for enjoyment of consumption and leisure) against the expected benefits that derive from increasing the likelihood of desirable state transitions (i.e., better odds of occupying states with increased HRQoL and reduced LPT).

---

26 Equation (24) suggests one can readily substitute the marginal utility of leisure for that of consumption on the LHS of the above expression, as these should be the same when optimality is achieved; analogously, Equation (25) indicates it does not matter whether we consider diet or exercise in the context of the RHS.

Given this research builds upon a model devised by Zweifel et al. (2009), it is not surprising their analysis culminates in a very similar expression (obtainable by combining their Equations 3.2.8 and 3.3.7), where t^c and t^I denote time allocated to consumption and health promotion, π denotes the probability of being ill tomorrow, $C_{h,1}$ refers to consumption for a healthy person today, and $u_x[C_2]$ is consumption tomorrow for a person in state *x* (they assume the planning horizon is sufficiently short that time preference can be ignored):

$$(27) \quad \left[\frac{\partial C}{\partial t^c}\right] \times \left[\frac{\partial u_h\left[C_{h,1}\right]}{\partial C_{h,1}}\right] = -\left[\frac{\partial \pi}{\partial t^I}\right] \times \left[u_h\left[C_2\right] - u_s\left[C_2\right]\right]$$

While there are differences between the two models—for example, I generalize from Zweifel et al. (2009) in assuming the individual can derive utility from leisure as well as consumption, and that people can act to reduce their risk of chronic illness in a variety of ways—this expression mirrors Equation (26) very closely. In particular, Equation (27) directs the decision-maker to invest in health such that the short-term pain this entails (i.e., the productivity of time allocated to consumption, multiplied by the marginal utility of consumption in the healthy state) just equals the expected longer-term gain (i.e., the productivity of time allocated to health promotion in reducing risk, multiplied by the difference in utility associated with the same level of consumption in each state).

Notwithstanding the usefulness of the insights derived from this discussion, it is important to reiterate, with reference to the introduction to Chapter 3, that the decision model is not actually amenable to solution through the application of analytical techniques. I return to this point in Section 4.2.3 below.

4.2 Solving the model

Dynamic programming (DP) techniques are well-suited for discrete-time optimization problems that incorporate stochasticity, such as this one. The essence of DP is that problems involving sequential decision-making can be broken into two parts. The individual solves the problem by optimizing in the present, taking advantage of the knowledge that they will also optimize in the future.

4.2.1 The Bellman equation

This above insight is reflected in the structure of the Bellman Equation, which is recreated below from Equation (10) in Chapter 2 (page 56) but now highlights the specific contribution of each model component described in Section 3:

$$\underbrace{V_t(s) = \max}_{(3)} \left\{ \underbrace{r_t(s,a)}_{(4)} + \underbrace{\delta \sum_{s' \in S} P_t(s' \mid s,a) V_{t+1}(s')}_{(5)} \right\}, \quad \underbrace{s \in S}_{(2)}, \quad \underbrace{}_{(1)} \tag{28}$$

Equation (28) can be interpreted as follows:

1) The problem consists of T periods. One decision is made during each period (i.e., the decision epochs).

2) Decisions are made with reference to the state the individual currently occupies (i.e., their age, employment status, health status, and duration of T2DM). Furthermore, in selecting a course of action, the individual must account for every state they may conceivably occupy in the future.

3) The individual aims to maximize their lifetime well-being, by working full-time or part-time, or retiring, and by adhering or not adhering to regular LTPA, healthy eating habits, and prescribed courses of pharmacotherapy. The highest level of well-being they can attain over their lives, given the state they now occupy, is captured by the *value function*. The individual must however "live within their means" and cannot make choices that require more time or income than they have available.

4) Lifetime well-being can be decomposed into the present value (PV) of current and expected future rewards. The amount of the current reward—how much well-being or utility the decision-maker gets to enjoy right now—depends on the state they occupy (i.e., their HRQoL) and the course of action chosen during this decision epoch (i.e., how much consumption and leisure they select). The *reward function* is the recipe the individual follows to generate satisfaction from these inputs.

5) Future rewards reflect how much well-being the decision-maker expects to enjoy over the remainder of their lives. It consists of the product of the following three elements:

    a) *Discount factor.* Because individuals typically prefer to consume now rather than later, future rewards are generally discounted. As such, the discount factor is typically lower than one.

    b) Transition probabilities. As state transitions occur randomly, individuals do not know exactly what the future holds for them. Instead, they form expectations about the future by estimating how likely they are to end up in other states next period, given this period's state and the choice they make. These transition probabilities then serve as weights applied to the next period's value function.

c) *Next-period value function.* As noted above, the value function reflects the highest level of well-being a person can attain over their lives, given their current state. Analogously, next period's value function denotes the maximum welfare achievable from next period until the final decision epoch. The presumption is that we can ascertain this amount despite not yet having done so for the current decision epoch. I now describe how this is done.

4.2.2 The backward induction algorithm

The individual solves the dynamic optimization problem (i.e., maximizes the value function) by constructing an optimal policy—a set of detailed instructions that stipulates what they should do during each decision epoch, in every state in which they may conceivably find themselves.

While there are exceptions (Rust, 1996, pp. 636–639), analytical solutions to DP problems are uncommon, necessitating the use of numerical techniques (Adda & Cooper, 2003, p. 33; Bertsekas, 2005, p. 25; Miranda & Fackler, 2004, pp. 1–5). Such techniques have previously been and continue to be applied in many areas of economics, ranging from optimal growth, multistage portfolio optimization and job search models (Cai & Judd, 2014; Sargent & Stachurski, 2017), to studies examining the incentives underpinning the decision to found a high-tech start-up or the impact of Medicaid on the purchase of private insurance (J. R. Brown & Finkelstein, 2008; Hall, 2010, Chapter 6), or attempting to explain historical growth in health expenditures (Hall & Jones, 2007).

Backward induction is particularly well-suited for discrete-time problems with finite horizons for which tractable closed-form solutions do not exist (Marescot et al., 2013, pp. 875–877). Section 3.3 in Chapter 2 highlighted the apparent paradox that to act now to maximize the PV of expected lifetime rewards requires information about next period's value function (i.e., $V_{t+1}(s')$ in Equation (28)) that in turn depends upon which choices were made today. In backward induction, the paradox is resolved by working backwards from the final period of a DP problem to the present, recursively identifying the optimal course of action in every possible state from that point onward. This is akin to choosing one's destination and then working backwards to determine the optimal route from the current location.

The backward induction algorithm is as follows (Judd, 1998, pp. 409–410; Miranda & Fackler, 2004, p. 190; Puterman, 2005, p. 92):

$$V_T(s) = U_T(s) \rightarrow \forall s \in S$$

Advance to the last period of the DP problem. For every state the person could occupy at that time, identify the largest reward (or within-period utility) they can attain. This is the value function

	for the last period, since there are no future periods.
$V_{t-1}\left(s_{t-1}\right) = \max_{x\in X(s)}\left\{\begin{array}{l} f_{t-1}\left(s_{t-1},x_{t-1}\right)+ \\ \delta\sum_{s_t\in S}P\left(s_t \mid s_{t-1},x_{t-1}\right)V_t\left(s_t\right)\end{array}\right\}$	Go back one period and do the same thing. This time, the value function for every state is the largest possible sum of the reward the person enjoys from their current action, and next period's value function.
$x^{*}_{t-1}\left(s_{t-1}\right) = \arg\max_{x\in X(s)}\left\{\begin{array}{l} f_{t-1}\left(s_{t-1},x_{t-1}\right)+ \\ \delta\sum_{s_t\in S}P\left(s_t \mid s_{t-1},x_{t-1}\right)V_t\left(s_t\right)\end{array}\right\}$	For every state, identify the action required to achieve the value function. This now forms part of the optimal policy.
	Repeat steps 2 and 3 until we reach the first period of the problem.

Although the backward induction algorithm can be implemented manually (for examples, see Ibe (2013, pp. 386–389) and Nahin (2007, pp. 312–329), or refer to the worked examples in Section 4.3 below), this is impractical when the action/state space and/or number of periods is large, as is the case here. However, the backward induction algorithm can be automated using a variety of software packages. This thesis solves the dynamic optimization problem outlined above in MATLAB using Paul Fackler's (2014) MDPSolve Toolbox.

4.2.3 Contrasting the analytic and numerical approaches to optimization

In Section 4.1 above, I noted that the analytic techniques employed to derive optimality conditions for the ZBK model and a simplified version of the decision model cannot be applied to the decision model itself. I now elaborate further, armed with the concepts and terminology introduced in Sections 4.2.1 and 4.2.2,.

In the ZBK model, the economic agent has the capacity to adjust the choice variables as finely as needed to maximize their objective function (conditional on satisfying any constraints to which they may be subject) and achieve the optimality condition, which is to say their choice set is continuous. By contrast, the set of possible actions in the decision model is clearly discrete; as noted in Section 3.3.4, one out of a maximum of 24 distinct actions can be taken during any decision epoch, and the range of options actually open to a person will typically be far narrower. This implies there is no guarantee any choice will precisely satisfy the optimality condition identified through the application of analytical techniques.

Put another way, whereas optimization in the ZBK model is akin to turning a knob on a radio to acquire a specific frequency, the economic agents confronting the optimization problem outlined in this thesis more closely resemble restaurant patrons consigned to selecting from a preset menu, who may choose any item consistent with their preferences but have no guarantee any has the precise combination of features (e.g., price, flavour, nutritional content, etc.) that would maximize their well-being. One can readily derive a more formal expression of this idea through straightforward manipulation of the Bellman Equation, where x_1 and x_0 below are distinct courses of action entailing high and low levels of health investment:

$$(29) \quad \begin{aligned}&\delta^{-1}\left[f\left(s,x_1\right)-f\left(s,x_0\right)\right]\leq \\ &\sum_{s'\in S}P\left(s'\mid s,x_0\right)V_{t+1}\left(s'\right)-\sum_{s'\in S}P\left(s'\mid s,x_1\right)V_{t+1}\left(s'\right)\end{aligned}$$

The LHS of the expression refers to the increase or decrease in within-period rewards the individual realizes when they invest in health, expressed in future value terms. Relative to the status quo, health investment typically manifests in a decline in within-period rewards, because it entails a short-term sacrifice of income and time that could otherwise be allocated to consumption and leisure, respectively. The RHS, meanwhile, denotes the resultant differences in the weighted sum of period $t + 1$ value functions. We would expect such differences to favour health investment, because healthier choices should increase (decrease) the likelihood of (un)desirable state transitions (e.g., by reducing the risk of developing T2DM) and enhance future rewards (e.g., by preventing or delaying decrements to HRQoL associated with diabetic complications).

An alternative expression that more closely reflects the features of the decision model is as follows, where I have now introduced the reward function and have further specified that each element of the action space entails a predefined level of commitment to LTPA, healthy eating habits and pharmacotherapy:

$$\delta^{-1} f(h) \times \left[\left[\alpha c_{1,t}^{\rho} + (1-\alpha)\ell \right.\right. \quad {}^{1} \qquad \ell \quad \left. {}^{1} \right]$$

$$(30) \qquad \sum_{h' \in H} P\left(h' \mid h, LTPA_0, Diet_0, Meds_0\right) V_{t+1}(h') -$$

$$\sum_{h' \in H} P\left(h' \mid h, LTPA_1, Diet_1, Meds_1\right) V_{t+1}(h')$$

In summary, one can conceptualize optimization under the numerical approach as the process of making pairwise comparisons between possible courses of action by contrasting the sum of current and expected future rewards and selecting the most highly ranked option. As already noted, the option ultimately chosen will depend on such factors as the individual's preferences, the impact of illness on well-being, and the level of risk reduction attainable through health investment. The next section aims to make these ideas concrete by demonstrating the calculation of rewards and value functions and the implementation of the backward induction algorithm.

4.3 Worked examples

I begin by elaborating on the objective function and constraints that serve as the backbone of the decision model, and that were briefly discussed in Sections 3.4 (i.e., Equation (14)) and 3.5 (i.e., Equations (16) and (17)) above, respectively. To this end, the table below re-presents these model components, reviews their interpretation, and characterizes the derivation of their constituent parts:

Equation	Variable	Definition
Reward Function		
(14) $u_t = f(h_t) \times \left[\alpha c_t^{\rho} + (1-\alpha) \ell \right.$ [illegible] ^{1} **Description:** Within-period reward function **Notes:** h_t reflects a combination of health status (i.e., healthy or diabetic), age, and duration of T2DM. $f(h_t)$ is equal to one for healthy individuals, and to zero for those who are deceased. For individuals with T2DM, $f(h_t)$ reflects average outcomes within UKPDS-OM2 simulated cohorts.	U_t α c_t ℓ_t $f(h_t)$ ρ	Reward (within-period utility) Preference parameter Consumption Leisure HRQoL $\rho = ((\sigma - 1)/\sigma)$, where σ reflects elasticity of substitution
Income Constraint		
(16) $p^c c_t = \underbrace{Y_t}_{Eq.16a} - \underbrace{[illegible]}_{[illegible]} \underbrace{[illegible]}_{[illegible]}$ **Description:** Individual consumption **Notes:** Consumption spending may not exceed income net of deductions and household expenditures. Consumption itself is expressed in units (since we can divide the RHS of the expression by price).	p^c c_t Y_t $Deduct_t$ $HealthExp_t$	Price of consumption Consumption Income Deductions from income Health-related expenditures
(16a) $Y_t = \left\{ \begin{array}{l} w_t \times LFS_t \times Emp_t \times \\ \left[\left[T_W^{PT} + \left(\Delta T_W^{PT \to FT} \times FT_t \right) \right] \right] \end{array} \right\}$ $+ \left\{ LFS_t \times (1 - Emp_t) \times EIA_t \right\}$ $+ \left\{ (1 - LFS_t) \times (CPP_t + OAS_t + GIS_t) \right\}$ $+ Senior_t \times Assets_t$ **Description:** Individual income **Notes:** Employment income, EIA, and retirement income are mutually exclusive—only one can be collected at any time. Income from liquidation of assets is age-dependent and paid out irrespective of labour force status (LFS). Labour force participation and full-time work are binary	Y_t w_t LFS_t Emp_t FT_t T_W Δ EIA_t CPP_t OAS_t GIS_t	Income Hourly wage Labour force participation Employment status Full-time work status Time worked (superscript denotes hours worked) Increment (difference in work hours between PT, FT status) Social assistance Canada Pension Plan Old Age Security Guaranteed Income Supplement

Equation	Variable	Definition
variables (e.g., for a full-time worker, LFS_t = FT_t = 1), enabling remuneration to be specified in a context where labour supply assumes a limited range of values.	$Senior_t$ $Assets_t$	Age 65+ Income from liquidating accumulated assets
(16b) $Deduct_t = Tax_t + EffLoss_t + \left\{ \begin{array}{l} LFS_t \times Emp_t \times \\ \left[CPP_t^{con} + EI_t^{con} + (1 - Senior_t) \times Sav_t \right] \end{array} \right\}$ **Description:** Deductions from individual income **Notes:** Savings are a predefined proportion of income deducted prior to calculation of income tax (akin to an RRSP) each year until reaching the standard age of retirement. The individual makes CPP and EI contributions for as long as they are working.	Ded_t Tax_t $EffLoss_t$ LFS_t Emp_t CPP_t^{con} EI_t^{con} $Senior_t$ Sav_t	Deductions from gross income Income tax Work efficiency losses Labour force participation Employment status CPP contributions EI contributions Age 65+ Personal savings
(16c) $HealthExp_t = \left[p_{LTPA}^{DA} + \left(\Delta p_{LTPA}^{DA \to A} \times LTPA_t \right) \right] + \left[p_{Diet}^{DA} + \left(\Delta p_{Diet}^{DA \to A} \times Diet_t \right) \right] + \left[p_{Meds}^{DA} + \left(\Delta p_{Meds}^{DA \to A} \times Meds_t \right) \right]$ **Description:** Individual health-related expenditures **Notes:** Prices are conceptualized in terms of units of adherence, as defined in Section 2.3 above. Adherence is binary in this model, so prices simply reflect the cost of adhering or not adhering to specific health behaviours.	$HealthExp_t$ **"Prices" of (superscripts denote adherence level):** P_{LTPA} P_{Diet} P_{Meds} Δ **Level of adherence to:** $LTPA_t$ $Diet_t$ $Meds_t$	Health-related expenditures Physical activity Healthy eating habits Medication adherence Increment (price differences attributable to health choices) Physical activity Healthy eating habits Prescribed medications
Time Constraint		
(17) $\ell \quad {}^{isc} - T_t^{Disc}$ ($Eq.17a$, $Eq.17b$) **Description:** Individual leisure **Notes:** Leisure, expressed in terms of hours per year, is the difference between total time available, and time allocated to non-discretionary and (other) discretionary activities.	ℓ_t Ω T_t^{Disc} T_t^{NDisc}	Leisure Total available time Discretionary time use (excepting leisure) Non-discretionary time use
	T_t^{NDisc}	Non-discretionary time use

Equation	Variable	Definition
(17a) $T_t^{NDisc} = T_{Sleep} + T_{Sick} + \left(T_{LTPA}^{DA} + T_{Diet}^{DA} + T_{Meds}^{DA}\right) + LFS_t \times \left[Emp_t \times T_W^{PT} + \left(1 - Emp_t\right) \times T_{Search}\right]$ **Description:** Non-discretionary time use **Notes:** Sick time is expressed as hours of lost productivity attributable to absenteeism and presenteeism both within and outside the workplace.	LFS_t	Labour force participation
	Emp_t	Employment status
	Time requirement for (superscripts denote adherence/involvement level):	
	T_{Sleep}	Time allocated to sleep
	T_{Sick}	Time lost to illness
	T_W	Time worked
	T_{LTPA}	Physical activity
	T_{Diet}	Healthy eating habits
	T_{Meds}	Medication adherence
	T_{Search}	Time allocated to job search
(17b) $T_t^{Disc} = LFS_t \times \left[Emp_t \times \left(\Delta T_W^{PT \to FT} \times FT_t\right)\right] + \left(\Delta T_{LTPA}^{DA \to A} \times LTPA_t\right) + \left(\Delta T_{Diet}^{DA \to A} \times Diet_t\right) + \left(\Delta T_{Meds}^{DA \to A} \times Meds_t\right)$ **Description:** Non-leisure discretionary time use **Notes:** Like prices, time requirements are conceptualized in terms of units of adherence/involvement; each variable conceptualized in these terms is dichotomous. As such, these requirements simply reflect the time needed to a) participate or not participate in the labour market; b) work full-time or part-time (contingent on participation); or, c) adhere or not adhere to specific health behaviours.	T_t^{Disc}	Discretionary time use (excepting leisure)
	LFS_t	Labour force participation
	Emp_t	Employment status
	Time requirement for (superscripts denote adherence/involvement level):	
	T_W	Time worked
	T_{LTPA}	Physical activity
	T_{Diet}	Healthy eating habits
	T_{Meds}	Medication adherence
	Δ	Increment
	Level of adherence to/involvement in:	
	FT_t	Full time work status
	$LTPA_t$	Physical activity
	$Diet_t$	Healthy eating habits
	$Meds_t$	Prescribed medications

4.3.1 Example #1

I consider the problem confronting a 93-year old woman of Asian-Indian ancestry recently diagnosed with T2DM. For the purposes of this example, I assume the individual possesses a university certificate, diploma, or degree at bachelor level or above.

As per the algorithm, the first step is to advance to the final decision epoch and calculate the largest attainable reward for every state the individual might occupy at that time. In the context of the decision model considered in this thesis, this is a trivial exercise: in the final epoch the only accessible state is deceased, which is associated with a reward of zero.

I now step back by a single decision epoch and repeat this exercise. Since retired individuals cannot re-enter the labour force, the person could conceivably occupy one of the following states:

Table 16: Achievable Year 1 states, 93-year-old decision-maker (Asian-Indian female) newly diagnosed with T2DM

Health state	Employment state	Adherence: LTPA		Adherence: Diet		Adherence: Medication	
		Period 1 (Years 0-9)	Period 2 (Years 10+)	Period 1 (Years 0-9)	Period 2 (Years 10+)	Period 1 (Years 0-9)	Period 2 (Years 10+)
T2DM	Unemployed (retired)	Adhere	N/A	Adhere	N/A	Adhere	N/A
T2DM	Unemployed (retired)	Adhere	N/A	Adhere	N/A	Don't adhere	N/A

Table 16: Achievable Year 1 states, 93-year-old decision-maker (Asian-Indian female) newly diagnosed with T2DM							
Health state	**Employment state**	**Adherence: LTPA**		**Adherence: Diet**		**Adherence: Medication**	
		Period 1 (Years 0-9)	**Period 2 (Years 10+)**	**Period 1 (Years 0-9)**	**Period 2 (Years 10+)**	**Period 1 (Years 0-9)**	**Period 2 (Years 10+)**
T2DM	Unemployed (retired)	Adhere	N/A	Don't adhere	N/A	Adhere	N/A
T2DM	Unemployed (retired)	Adhere	N/A	Don't adhere	N/A	Don't adhere	N/A
T2DM	Unemployed (retired)	Don't adhere	N/A	Adhere	N/A	Adhere	N/A
T2DM	Unemployed (retired)	Don't adhere	N/A	Adhere	N/A	Don't adhere	N/A
T2DM	Unemployed (retired)	Don't adhere	N/A	Don't adhere	N/A	Adhere	N/A
T2DM	Unemployed (retired)	Don't adhere	N/A	Don't adhere	N/A	Don't adhere	N/A
Dead	N/A	N/A	N/A	N/A	N/A	N/A	N/A

The value function for each state in Table 16 is the largest possible sum of the reward the person enjoys from their current action, and next period's value function. With reference to Equation (28), the above discussion suggests the value function for the next and final period is uniformly zero, implying the decision-maker need focus only on calculating the within-period reward. I therefore proceed by walking through the steps involved in these calculations for the case in which the patient has a history of full adherence to LTPA, healthy eating and pharmacotherapeutic adherence, beginning with the observation that, as per Equation (14), the within-period reward is a function of consumption, leisure, and current health state.

Estimating consumption

Equation (16) indicates that consumption is simply the difference between household income and the sum of income deductions (the sum of provincial and federal taxes, CPP/EI contributions, personal savings, and productivity losses) and health-related expenditures:

$$p^c c_t = \underbrace{Y}_{1} - \underbrace{Deduct}_{2} - \underbrace{HealthE}_{3}$$

The figures beneath the equation correspond to the following:

1) *Household income—denoted by Equation (16a).* Because they are retired, the individual's annual income is \$25,954.64, consisting of \$13,370, \$7,025.88 and \$5,558.76 in CPP, OAS and GIS payments, respectively (see Table 6 on page 120). Since the model does not permit retirees to work and receive public pensions concurrently, and since it is assumed individuals living to advanced ages will have exhausted private savings, these are the only sources of income available to the decision-maker.

2) *Deductions from income—denoted by Equation (16b).* \$20,395.88 (i.e., the sum of CPP and OAS payments) is taxable income (GIS payments are not considered taxable income). Combined provincial and federal tax rates are

such that a marginal rate of 10.8% is applied to every dollar of taxable income between \$9,383 and \$11,810, while a rate of 25.8% is applied to every dollar between \$11,810 and \$31,843. This implies that the individual's tax bill should amount to \$262.01 + \$2,215.16 = \$2,477.17. Being retired, the individual does not make CPP or EI contributions, nor do they invest any part of their income. Finally, because the individual is retired, efficiency losses associated with diabetic complications have no bearing on their income. In summary, deductions from personal income are as follows:

$$
\begin{aligned}
Deduct_t &= Tax_t + EffLoss_t \\
&\quad + \left\{ \begin{aligned} & LFS_t \times Emp_t \times \\ & \left[CPP_t^{con} + EI_t^{con} + \left(1 - Senior_t\right) \times Sav_t \right] \end{aligned} \right\} \\
&= \$2,477.17 + \$0.00 + \left\{ 0 \times 0 \times \left[CPP_t^{con} + EI_t^{con} + 0 \times Sav_t \right] \right\} \\
&= \$2,477.17
\end{aligned}
$$

3) *Health-related expenditures—denoted by Equation (16c).* We have assumed that the decision-maker is compliant with LTPA, healthy eating habits and pharmacotherapy. The decision model presently assumes LTPA is costless (see page 119 in Section 3.5.1). In addition, for a female of Asian-Indian extraction in the 25-44 age range, the methodology outlined in Appendix B yields an estimated annual dietary cost of \$3,164.41 (see

Table 8 on page 129).the cost of maintaining a healthy diet is calculated at $2,144.55 (Table 8). The Manitoba Pharmacare deductible rate for 2019/20 for individuals in this income bracket (based upon gross income) is 4.79%, or $1,243.23. Having been recently diagnosed, the costs of pharmacotherapy for this individual are relatively modest ($922.68 per year) (see Table 35 in Appendix C); since the individual's Pharmacare deductible exceeds their drug costs, they are liable for the entire amount. Thus, household expenditures are as follows:

$$
\begin{aligned}
HealthExp_t \quad &= \left[p_{LTPA}^{DA} + \left(\Delta\, p_{LTPA}^{DA \to A} \times LTPA_t \right) \right] + \left[p_{Diet}^{DA} + \left(\Delta\, p_{Diet}^{DA \to A} \times Diet_t \right) \right] + \\
&\left[p_{Meds}^{DA} + \left(\Delta\, p_{Meds}^{DA \to A} \times Meds_t \right) \right] = \left[\$0.00 + \left(\$0.00 \times 1 \right) \right] + \\
&\left[\$4,300.98 + \left(-\$2,156.43 \times 1 \right) \right] + \left[\$0.00 + \left(\$922.68 \times 1 \right) \right] \\
&= \$0.00 + \$2,144.55 + \$922.68 = \$3,067.23
\end{aligned}
$$

Since the model assumes the per-unit price of consumption (i.e., p^c) to be one dollar, by default, final consumption is as follows:

$$
\begin{aligned}
&p^c c_t = Y_t - Deduct_t - HealthExp_t \Rightarrow c_t = \left(Y_t - Deduct_t - HealthExp_t \right) \big/ p^c \\
&c_t = \left(\$25,954.64 - \$2,477.17 - \$3,067.23 \right) \big/ \$1.00 = 20,410.24
\end{aligned}
$$

<u>*Estimating leisure*</u>

According to Equation (17), the time for leisure is given by the difference between the total time available, and time allocated on a discretionary or non-discretionary basis to a range of possible activities:

$$\ell \qquad {}_{t}^{NDisc} - T_{t}^{Disc}$$

$$1 \qquad 2 \qquad 3$$

1) There is a total of 8,760 hours in each year.

2) *Non-discretionary time use—denoted by Equation* (17a). Uses of time over which the individual exercises limited discretion include sleeping and illness (Section 3.5.2):

    a. The model assumes Canadians spend about one-third of each day sleeping (i.e., 2,920 hours per year) (page 131).

    b. Pursuing the approach outlined in Section 3.5.3 produces the result this individual will lose approximately 100.74 hours-equivalent to illness each year (i.e., 28.02 and 6.48 hours of absenteeism and presenteeism, respectively, multiplied by 2.92 to reflect illness experienced outside of workplace settings).[27]

$$
\begin{aligned}
T_t^{NDisc} &= T_{Sleep} + T_{Sick} + \left(T_{LTPA}^{DA} + T_{Diet}^{DA} + T_{Meds}^{DA}\right) \\
&\qquad + LFS_t \times \left[Emp_t \times T_W^{PT} + \left(1 - Emp_t\right) \times T_{Search}\right] \\
&= 2{,}920.00 + 100.74 + \left(0.00 + 182.50 + 0.00\right) \\
&\qquad + 0 \times \left[0 \times 1{,}000.00 + 0 \times 494.00\right] \\
&= 2{,}920.00 + 100.74 + 182.50 = 3{,}203.24
\end{aligned}
$$

3) *Discretionary time use—denoted by Equation* (17b). Discretionary uses of time include work and participation in health-promoting activities:

    a. Retirees may not subsequently re-enter the labour force; such individuals therefore allocate no time to work (page 135).

    b. The individual has, in this instance, chosen to participate in LTPA, engage in healthy eating habits and adhere to prescribed medications. Time required to self-administer medications is assumed to be modest (page 136), but LTPA and healthy eating

27 The latter figure can be derived from Section 3.5.3 (Table 7). The former value, however, is obtained from UKPDS-OM2 simulations, the results of which are not presented in this thesis in their entirety.

habits consume 130 and 547.5 hours of her time each year, respectively (page 136).

$$
\begin{aligned}
T_t^{Disc} &= LFS_t \times \left[Emp_t \times \left(\Delta T_W^{PT \to FT} \times FT_t \right) \right] + \left(\Delta T_{LTPA}^{DA \to A} \times LTPA_t \right) \\
&\quad + \left(\Delta T_{Diet}^{DA \to A} \times Diet_t \right) + \left(\Delta T_{Meds}^{DA \to A} \times Meds_t \right) \\
&= 0 \times \left[0 \times (1{,}000.00 \times 0) \right] + (130.00 \times 1) + (365.00 \times 1) + (0.00 \times 1) \\
&= 0.00 + 130.00 + 365.00 + 0.00 = 495.00
\end{aligned}
$$

We can now readily calculate the time remaining for leisure by subtracting time allocated by or lost to the decision-maker from the total amount available:

$$
\ell \qquad {}_t^{\neg NDisc} - T_t^{Disc} = 8,760.00 - 3,203.24 - 495.00 = 5,061.76
$$

<u>HRQoL</u>

HRQoL is dependent upon how long an individual has lived with T2DM, and on their history of adherence to LTPA, healthy eating habits, and pharmacotherapy. The HRQoL values themselves are derived from simulations undertaken using the UKPDS-OM2, and implicitly reflect the accumulation of diabetic complications within the simulated cohort. For a 94-year-old female of Asian-Indian extraction who has lived with T2DM for one year, the simulated HRQoL score is 0.8025.

<u>Calculating utility</u>

The above calculations furnish the model with the elements necessary to estimate the within-period reward, excepting the elasticity of substitution, ρ, and the distribution parameter, α—which, as noted in Sections 3.4.2 and 3.4.3, are set by default to 0 and 0.5, respectively. This enables me to apply Equation (14) to calculate the individual's utility, noting that although the CES function ceases to be well-defined at $\rho = 0$, it approaches the Cobb-Douglas function in the limit (Nechyba, 2011, p. 182):

Extending the exercise

I have so far considered the reward associated with only one of the eight possible choices the decision-maker could have made for only one of the nine possible states they could conceivably occupy at the beginning of their 95th and final year of life. Fortunately, however, the volume of calculations to be undertaken is significantly reduced by the fact the model only permits individuals to revisit their health-related choices at specific points in time (i.e., upon diagnosis, and again nine years later). To enforce this assumption, the model applies a large penalty when choices made outside these decision epochs differ from the individual's adherence history, thereby overriding Equation (14).

This has two implications. First, the individual maximizes well-being by pursuing the course of action to which they committed at an earlier point in time, meaning we can effectively disregard all other possible choices. Second, because this consideration applies to all states the person could occupy, we can neatly summarize the calculation of the value function for each in the following table:

Table 17: Achievable Year 1 states, 93-year-old decision-maker (Asian-Indian female) newly diagnosed with T2DM										
Health state	**Empl. state**	**Adherence: LTPA**		**Adherence: Diet**		**Adherence: Medication**		**Maximum achievable reward**	$\delta\Sigma p V_{t+1}$ **(Year 2)**	**Value function (Year 1)**
		P1	**P2**	**P1**	**P2**	**P1**	**P2**			
T2DM	U	A	N/A	A	N/A	A	N/A	8,156.83	0	8,156.83
T2DM	U	A	N/A	A	N/A	DA	N/A	8,330.45	0	8,330.45
T2DM	U	A	N/A	DA	N/A	A	N/A	7,945.68	0	7,945.68
T2DM	U	A	N/A	DA	N/A	DA	N/A	8,081.02	0	8,081.02
T2DM	U	DA	N/A	A	N/A	A	N/A	8,226.70	0	8,226.70
T2DM	U	DA	N/A	A	N/A	DA	N/A	8,338.16	0	8,338.16
T2DM	U	DA	N/A	DA	N/A	A	N/A	7,894.38	0	7,894.38
T2DM	U	DA	N/A	DA	N/A	DA	N/A	8,076.41	0	8,076.41
Dead	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0	0	0

Of note is that the Year 1 value function is equal to the maximum reward achievable in Year 1. This occurs because the transition to being deceased between the 94th and 95th years of life occurs with certainty, and because the reward associated with occupation of the deceased state is zero. We apply Equation (28) to illustrate this for the case in which the individual elects to adhere to LTPA and healthy eating but *not* to prescribed courses of pharmacotherapy:

$$V_t(s) = \max_{x \in X(s)} \left\{ f(s,x) + \delta \sum_{s' \in S} P(s' | s,x) V_{t+1}(s') \right\}, s \in S, t = 1, 2$$
$$= [8,330.45 + 0.95 \times (1 \times 0)] = 8,330.45$$

In summary, the Year 1 value function for each state is equal to their within-period reward, while the optimal policy simply involves pursuing the course of action dictated by the individual's adherence history.

Full circle

Since the analysis is occurring from the vantage of a 93-year-old Asian-Indian female recently diagnosed with T2DM, it is necessary to step back one more period. The choices available to this decision-maker are as follows:

Table 18: Available choices for a 93-year-old decision-maker (Asian-Indian female) newly diagnosed with T2DM

Adherence: LTPA	Adherence: Diet	Adherence: Medication	Maximum achievable reward	$\delta\Sigma pV_{t+1}$ (Year 1)	Value function (Year 0)
Adhere	Adhere	Adhere	8,201.31	6,550.45	14,751.76
Adhere	Adhere	Don't adhere	8,305.23	6,689.88	14,995.11
Adhere	Don't adhere	Adhere	8,028.85	6,380.88	14,409.73
Adhere	Don't adhere	Don't adhere	8,123.82	6,489.58	14,613.40
Don't adhere	Adhere	Adhere	8,384.64	6,606.56	14,991.20
Don't adhere	**Adhere**	**Don't adhere**	**8,490.88**	**6,696.07**	**15,186.96**
Don't adhere	Don't adhere	Adhere	8,229.26	6,339.69	14,568.96
Don't adhere	Don't adhere	Don't adhere	8,326.61	6,485.87	14,812.48

Examination of the values in the final column of the table indicates that the optimal policy for a newly-diagnosed 93-year-old female retiree of Asian-Indian ancestry is to adhere with healthy eating habits—but not with regular physical activity or prescribed medications—in the year of diagnosis and the subsequent year. The value function for this individual is 15,186.96 *utils* which, by definition, is the highest level of well-being the individual can hope to achieve, given her state when she must make her decision.

In contrast to the decision their future self will make at age 94, here the decision-maker will apply a discount factor δ to the expectation of next period's value function (at age 94 there is nothing to discount, since there are no additional periods to consider). By default, the model applies a discount factor of 0.95 (page 181). It should also be recognized that the probability of mortality in the year of diagnosis depends only upon the individual's state and not the action taken—although since choices made upon diagnosis subsequently form part of the individual's adherence history, such choices will tend to have a lasting impact on life expectancy (at age 93, there is no such impact, since the decision enters the individual's adherence history in a year where mortality occurs with certainty).

4.3.2 Example #2

In the second worked example, I examine health-related decision-making from the vantage of a 60-year-old employed Caucasian male who has lived with T2DM for 9 years. For the purposes of this discussion, I assume the individual possesses a high school diploma or equivalent level of educational attainment. I further assume the individual has not, on balance, managed their condition well in previous years, having adhered faithfully to regular physical activity but not to healthy eating of prescribed courses of pharmacotherapy.

This worked example is distinct from the previous one in that from a modelling (and a statistical) standpoint, end-of-line for the decision-maker is still many years off, meaning one would need to work backwards recursively through 35 decision epochs to fully characterize the individual's optimal policy. As such, I focus here primarily on the calculation of within-period rewards, taking next period's value functions as given; however, I also use this opportunity to illustrate how decision-makers with an established history of adherence or non-adherence to health-promoting activities form expectations concerning future health outcomes, and how this influences their choices in the present.

Analogous to the previous worked example, Table 19 lists all states the decision-maker may experience in Year 1, given their current circumstances:

Table 19: Achievable Year 1 states, 60-year-old decision-maker (Caucasian male) with T2DM (duration—9 years)							
Health state	**Employment state**	**Adherence: LTPA**		**Adherence: Diet**		**Adherence: Medication**	
		Period 1 (Years 0-9)	**Period 2 (Years 10+)**	**Period 1 (Years 0-9)**	**Period 2 (Years 10+)**	**Period 1 (Years 0-9)**	**Period 2 (Years 10+)**
T2DM	Employed	Adhere	Adhere	Don't adhere	Adhere	Don't adhere	Adhere
T2DM	Employed	Adhere	Don't adhere	Don't adhere	Adhere	Don't adhere	Adhere
T2DM	Employed	Adhere	Adhere	Don't adhere	Don't adhere	Don't adhere	Adhere
T2DM	Employed	Adhere	Don't adhere	Don't adhere	Don't adhere	Don't adhere	Adhere
T2DM	Employed	Adhere	Adhere	Don't adhere	Adhere	Don't adhere	Don't adhere
T2DM	Employed	Adhere	Don't adhere	Don't adhere	Adhere	Don't adhere	Don't adhere
T2DM	Employed	Adhere	Adhere	Don't adhere	Don't adhere	Don't adhere	Don't adhere
T2DM	Employed	Adhere	Don't adhere	Don't adhere	Don't adhere	Don't adhere	Don't adhere
T2DM	Unemployed	Adhere	Adhere	Don't adhere	Adhere	Don't adhere	Adhere
T2DM	Unemployed	Adhere	Don't adhere	Don't adhere	Adhere	Don't adhere	Adhere
T2DM	Unemployed	Adhere	Adhere	Don't adhere	Don't adhere	Don't adhere	Adhere
T2DM	Unemployed	Adhere	Don't adhere	Don't adhere	Don't adhere	Don't adhere	Adhere
T2DM	Unemployed	Adhere	Adhere	Don't adhere	Adhere	Don't adhere	Don't adhere
T2DM	Unemployed	Adhere	Don't adhere	Don't adhere	Adhere	Don't adhere	Don't adhere
T2DM	Unemployed	Adhere	Adhere	Don't adhere	Don't adhere	Don't adhere	Don't adhere
T2DM	Unemployed	Adhere	Don't adhere	Don't adhere	Don't adhere	Don't adhere	Don't adhere
Dead	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Table 19 illustrates two fundamental ways in which the choice confronting the decision-maker in this example is distinct from the one in the previous example. First, the model assumes people effectively cannot leave the labour force prior to the standard age of retirement (Section 3.2.2), but does account for the possibility they may experience bouts of unemployment due to circumstances beyond their control; thus, built into the decision-making calculus is an acknowledgement of the need to prepare for the impact of undesirable employment state transitions, should they occur, and also that individual will soon be in a position to retire even if they cannot do so immediately. Second, Table 19 demonstrates how, despite the "memorylessness" of MDPs, the model allows people to accumulate diverse adherence histories that, in turn, enable prior health-related decisions to have lasting impacts upon their well-being through their influence on HRQoL, the risk of mortality, and workplace absenteeism.

As before, the value function for each state in Table 19 is the largest possible sum of the reward the person enjoys from their current action, and next period's value function. For the reasons outlined above, I focus here on calculating the within-period reward for the case in which the patient opts to work full-time hours and elects to supplement their ongoing participation in LTPA with pharmacotherapy, but not healthy eating habits. I then compare the result with outcomes he expects to realize if he makes other choices.

Estimating consumption

As Equation (16) indicates, consumption is the difference between household income and the sum of income deductions (the sum of provincial and federal taxes, CPP/EI contributions, personal savings, and productivity losses) and health-related expenditures.

1) *Household income—denoted by Equation (16a).* The individual is employed during the decision epoch under consideration, and, by assumption, has chosen to work full-time hours. Based on an extrapolation from 2011 NHS data (see Table 5 in Section 3.5.1), the model assumes a healthy individual in this position would earn $50,369.10 annually, prior to imposition of taxes, CPP/EI deductions and private savings, and before having accounted for LPT attributable to illness.

2) *Deductions from income—denoted by Equation (16b).* Deductions from the individual's income ($19,853.12) consist of the following:

   a. *Private savings.* The enforced savings mechanism embedded in the model sets aside 10% of the individual's gross earnings ($5,036.91) in order to supplement other sources of retirement income. Of note is that the saving mechanism is intended to resemble contributing to RRSPs and, consequently, these sums do not constitute part of the individual's taxable income.

   b. *LPT (absenteeism and presenteeism).* For the purposes of this worked example, I've assumed the individual has historically managed their T2DM sub-optimally and, therefore, has begun to experience microvascular and/or macrovascular complications. By applying the methodology outlined in Section 3.5.3 and drawing from UKPDS-OM2 simulation results, I estimate the individual loses approximately 151.26 hours in productive time per year (i.e., 51.06 and 100.20 hours, respectively, due to workplace absences and efficiency losses). Since the individual's hourly remuneration is equivalent to $25.18, this translates into $3,809.42 in lost household income.

c. *Income tax.* The decision-maker has $41,522.90 after accounting for retirement contributions and LPT. A person in this tax bracket would be expected to pay a minimum of $5,430.52, and given a 27.75% marginal tax rate, this implies a total tax bill of $8,116.41 (i.e., $5,430.52 + 0.2775 × [$41,522.90 - $31,844.00]).

d. *CPP & EI contributions.* CPP contributions are the least of the maximum CPP contribution, and the product of the CPP contribution rate and the difference between the individual's adjusted income and the basic exemption (i.e., using 2017 program parameters, the lesser of $2,564.10 and 0.0495 × [$46,559.80 - $3,500.00] = $2,131.46). The EI contribution is calculated in a similar fashion, except that there is no basic exemption (i.e., the lesser of \$836.19 and 0.0163 × \$46,559.80 = \$758.92). Total CPP and EI contributions therefore amount to \$2,890.38.

3) *Health-related expenditures—denoted by Equation (16c).* In this example I have assumed compliance with LTPA and pharmacotherapy, but not healthy eating habits. LTPA does not involve a financial outlay (see page 119 in Section 3.5.1), but for a male of Caucasian ancestry in the 25-44 age range, the methodology outlined in Appendix B yields an estimated annual dietary cost of \$6,101.14 (see Table 8 on page 129). In addition, because the individual has historically not been vigilant in managing their T2DM, the costs of pharmacotherapy for this individual are substantial (\$5,716.40 per year) (see Table 35 in Appendix C); since this exceeds the individual's Pharmacare deductible (0.0564 × \$46,559.80), they are liable only for the latter. Household expenditures are therefore as follows:

$$
\begin{aligned}
HealthExp_t \quad &= \left[p_{LTPA}^{DA} + \left(\Delta\, p_{LTPA}^{DA \to A} \times LTPA_t \right) \right] + \left[p_{Diet}^{DA} + \left(\Delta\, p_{Diet}^{DA \to A} \times Diet_t \right) \right] \\
&+ \left[p_{Meds}^{DA} + \left(\Delta\, p_{Meds}^{DA \to A} \times Meds_t \right) \right] = \left[\$0.00 + \left(\$0.00 \times 1 \right) \right] \\
&+ \left[\$6{,}101.14 + \left(\text{-}\$2{,}140.37 \times 0 \right) \right] + \left[\$0.00 + \left(\$2{,}625.97 \times 1 \right) \right] \\
&= \$0.00 + \$6{,}101.14 + \$2{,}625.97 = \$8{,}727.11
\end{aligned}
$$

Since the model assumes the per-unit price of consumption (i.e., p^c) to be one dollar, by default, final consumption is as follows:

$$p^c c_t = Y_t - Deduct_t - HealthExp_t \Rightarrow c_t = \left(Y_t - Deduct_t - HealthExp_t\right) / p^c$$
$$c_t = \left(\$50,369.10 - \$19,853.12 - \$8,727.11\right) / \$1.00 = 21,788.98$$

<u>*Estimating leisure*</u>

With reference to Equation (17), the time for leisure is given by the difference between the total time available, and time allocated on a discretionary or non-discretionary basis to a range of possible activities:

$$\ell \qquad {}_{t}^{NDisc} - T_t^{Disc}$$
$$\underset{1}{} \quad \underset{2}{} \quad \underset{3}{}$$

1) There is a total of 8,760 hours in each year.

2) *Non-discretionary time use—denoted by Equation* (17a). Non-discretionary uses of time include those the individual must allocate to sleep, labour market (i.e., job search) and other activities, as well as LPT attributable to illness.

    a. *Sleep.* As in the first example, the model assumes Canadians spend about one-third of each day sleeping (i.e., 2,920 hours per year) (page 131).

b. *LPT.* As noted above, applying the methodology outlined in Section 3.5.3 and drawing from UKPDS-OM2 simulation results yields the estimate that the individual loses approximately 151.26 hours in productive time per year at work due to T2DM. However, the model supposes that LPT occurring in the workplace represents only a proportion of all time a person loses to illness, further assuming said proportion is equal to the share of waking hours allocated to generating income in the labour market (i.e., 34.2%). Proceeding in this way yields the result that 641.36 hours is lost to illness each year.

c. *Labour market activities.* As noted above, the model assumes that decision-makers who have not yet reached the standard age of retirement are compelled to work at least part-time hours (i.e., 1,000 hours per year).

d. *Other non-discretionary activities.* While individuals are under no obligation to commit any time to LTPA or self-administering medications (this decision-maker has chosen to adhere to both), the model assumes even those deciding not to adhere to healthy eating habits must allocate at least 30 minutes per day (182.5 hours per year) to meal preparation (see page 134).

In summary, non-discretionary time use is calculated as follows:

$$
\begin{aligned}
T_t^{NDisc} &= T_{Sleep} + T_{Sick} + \left(T_{LTPA}^{DA} + T_{Diet}^{DA} + T_{Meds}^{DA}\right) \\
&\quad + LFS_t \times \left[Emp_t \times T_W^{PT} + \left(1 - Emp_t\right) \times T_{Search}\right] \\
&= 2,920.00 + 641.36 + \left(0.00 + 182.50 + 0.00\right) \\
&\quad + 1 \times \left[1 \times 1,000.00 + 0 \times 494.00\right] \\
&= 2,920.00 + 641.36 + 182.50 + 1,000.00 = 4,743.86
\end{aligned}
$$

3) *Discretionary time use—denoted by Equation* (17b). Discretionary uses of time include work and participation in health-promoting activities:

    a. Although the individual is categorized as a full-time worker (i.e., 2,000 hours per year), I deduct the 51.06 hours lost to absenteeism for which they cannot avail themselves of paid sick days, meaning the decision-maker commits only 1,948.94 hours to the generation of labour market income. As implied above, however, only the final 948.94 hours is considered discretionary, since people who are classified as employed must work at least part-time hours (i.e., 1,000 hours per year).

b. The individual has chosen to participate in LTPA and adhere to prescribed medications, but not to eat healthfully. Engaging in regular physical activity necessitates committing 130.00 hours each year above and beyond the minimum level in which the decision-maker must partake to sustain themselves—which, in the context of this model, is nothing (page 136). In addition, I assume

    i. engaging in unhealthy eating habits is comparatively economical timewise, and that the allocation of time this entails approaches the minimum amount needed to feed oneself (i.e., none of this time would be considered discretionary);

    ii. and, time required to self-administer medications is modest (page 136).

$$
\begin{aligned}
T_t^{Disc} &= LFS_t \times \left[Emp_t \times \left(\Delta T_W^{PT \to FT} \times FT_t \right) \right] + \left(\Delta T_{LTPA}^{DA \to A} \times LTPA_t \right) \\
&\quad + \left(\Delta T_{Diet}^{DA \to A} \times Diet_t \right) + \left(\Delta T_{Meds}^{DA \to A} \times Meds_t \right) \\
&= 1 \times \left[1 \times (948.94 \times 1) \right] + (130.00 \times 1) + (365.00 \times 0) + (0.00 \times 1) \\
&= 948.94 + 130.00 + 0.00 + 0.00 = 1{,}078.94
\end{aligned}
$$

Time available for leisure is then as follows:

$$\ell \qquad {}_{t}^{\neg NDisc} - T_{t}^{Disc} = 8,760.00 - 4,743.86 - 1,078.94 = 2,937.18$$

HRQoL

As in the previous example, the model derives HRQoL values from simulations undertaken using the UKPDS-OM2, and implicitly reflect the accumulation of diabetic complications within simulated cohort of patients. For a 60-year-old male of Caucasian extraction who has lived with T2DM for nine years and who has previously adhered to LTPA, but not healthy eating habits or pharmacotherapy, the simulated HRQoL score is 0.7951.

Calculating utility

Applying Equation (14) now enables me to calculate the individual's utility (to avoid repetition, I refer readers to the previous example for the rationale underpinning the choice of parameter values):

$$\begin{aligned} u_t &= f(h_t) \times \left[\alpha c_t^{\rho} + (1-\alpha)\ell \quad {}^{1} \quad \ell \right. \\ &= 0.7951 \times (21,788.98)^{0.5} (2,937.18)^{0.5} = 6,361.06 \end{aligned}$$

Similar results for the other courses of action open to the decision-maker are presented in Table 25 below.

Extending the exercise

Table 24 illustrates the calculation of the present value of the expectation over next period's value functions for every viable choice within their action space:

Table 20: Available choices for a 60-year-old decision-maker (Caucasian male), with T2DM (duration—9 years)							
Work hours	**Adherence**			**Employed**	**Unemployed**	**Dead**	$\delta \Sigma p V_{t+1}$ (δ = 0.95)
	LTPA	**Diet**	**Medication**	*Probabilities*			
				0.9397	*0.0396*	*0.0207*	
Full-time	Adhere	Adhere	Adhere	81,355.70	76,682.30	0.00	75,512.52
Full-time	**Don't adhere**	**Adhere**	**Adhere**	**86,509.19**	**81,704.94**	**0.00**	**80,302.08**
Full-time	Adhere	Don't adhere	Adhere	84,548.89	78,535.17	0.00	78,432.88
Full-time	Don't adhere	Don't adhere	Adhere	81,288.95	75,204.72	0.00	75,397.39
Full-time	Adhere	Adhere	Don't adhere	76,668.06	71,470.39	0.00	71,131.73
Full-time	Don't adhere	Adhere	Don't adhere	80,425.22	75,125.65	0.00	74,623.33
Full-time	Adhere	Don't adhere	Don't adhere	78,267.07	71,729.24	0.00	72,568.97
Full-time	Don't adhere	Don't adhere	Don't adhere	75,350.09	68,724.25	0.00	69,851.89
Part-time	Adhere	Adhere	Adhere	81,355.70	76,682.30	0.00	75,512.52
Part-time	Don't adhere	Adhere	Adhere	86,509.19	81,704.94	0.00	80,302.08
Part-time	Adhere	Don't adhere	Adhere	84,548.89	78,535.17	0.00	78,432.88
Part-time	Don't adhere	Don't adhere	Adhere	81,288.95	75,204.72	0.00	75,397.39
Part-time	Adhere	Adhere	Don't adhere	76,668.06	71,470.39	0.00	71,131.73
Part-time	Don't adhere	Adhere	Don't adhere	80,425.22	75,125.65	0.00	74,623.33
Part-time	Adhere	Don't adhere	Don't adhere	78,267.07	71,729.24	0.00	72,568.97
Part-time	Don't adhere	Don't adhere	Don't adhere	75,350.09	68,724.25	0.00	69,851.89

To avoid repeating the explanations accompanying the previous worked example, I simply note the following:

- That the model only permits individuals to revisit their health-related choices at specific points in time (i.e., upon diagnosis, and again nine years later) implies that in every period after this one, the decision-maker maximizes well-being by pursuing the course of action to which they committed at an earlier point in time. The only remaining choices the patient in this example will make, concern the extent of labour market participation and the timing of retirement.

- The "employed" and "unemployed" states referenced above the shaded box in Table 24 do not uniquely identify the individual's circumstances in Year 1 and beyond, which also include the individual's history of adherence to LTPA, healthy eating habits and pharmacotherapy. This enables the consequences of prior health-related decisions to "follow the patient around" by exerting an ongoing influence on their HRQoL, LPT, and risk of mortality.

- The probabilities themselves do not vary with the individual's choice, because the model implicitly assumes the impact of changes in health-related behaviour on the risk of mortality would not manifest immediately but would instead be realized over time—beginning, in this context, in the period after the choice is made.

As noted throughout this worked example, the decision model allows earlier patterns of health behaviour among individuals diagnosed with T2DM to exert a lasting influence on their well-being in subsequent periods. It accomplishes this by assigning patients to states that correspond to the choices they made upon diagnosis with T2DM, and again nine years later.[28] With reference to Table 19 above, which presents a complete list of these states, I note the following:

- I have arbitrarily assumed that upon diagnosis (i.e., several years prior to the decision epoch under consideration), this patient chose to adhere to LTPA, but not healthy eating habits or pharmacotherapy. All states he will subsequently occupy reflect this, even if he makes different choices for himself in the current decision epoch. Intuitively, poor health-related choices made upon diagnosis can result in accumulation of organ and tissue damage that cannot be readily undone through subsequent lifestyle modification—although it is certainly possible to take steps to limit further harm.

- In this worked example, the patient confronts another similar decision. As Table 19 indicates, upon making this choice the patient will have compiled an adherence history documenting past decisions regarding participation in LTPA, dietary intake and medication compliance, both upon diagnosis and again several years later. In its current formulation, the model does not permit the individual to subsequently adjust their health behaviours (the rationale for

[28] This is achieved by engineering the modification of the stochastic process so that a given combination of health-related behaviours precludes the possibility of transitioning to any states *other* than those corresponding to that choice—aside, of course, from the deceased state.

this is outlined in Section 2.2 above), so his choices today have significant implications for his future well-being.

- ❖ Consequently, a fully-rational, forward looking decision-maker in this situation will weigh his options carefully. He will be aware that investing in health implies a long-term commitment to regular LTPA, healthy eating habits and/or pharmacotherapy, which may necessitate diverting resources that could otherwise be allocated to consumption and leisure; however, he will also recognize that these same investments can help to manage the progression of T2DM and its complications in ways that manage LPT, slow the erosion of HRQoL, and reduce the risk of mortality.

To illustrate the long-term implications of the patient's decision and the factors motivating their choice, Table 21 contrasts the future state of affairs confronting his retired future self at age 70 when he invests optimally in his health (i.e., Choice #1) versus when he opts not to adhere to LTPA, healthy eating habits or pharmacotherapy (i.e., Choice #2)—assuming, of course, that the he has managed to survive to that age:

Table 21: 60-year-old decision-maker (Caucasian male), with T2DM (duration—9 years)

Measure	Choice #1 (Optimal)	Choice #2 (Non-Adherent)	Absolute Difference
Personal attributes and current status			
Current age	70 years old	70 years old	

Table 21: 60-year-old decision-maker (Caucasian male), with T2DM (duration—9 years)							
Measure	**Choice #1 (Optimal)**			**Choice #2 (Non-Adherent)**			**Absolute Difference**
Health Status	T2DM, 19 years			T2DM, 19 years			
Employment Status	Unemployed (Retired)			Unemployed (Retired)			
Adherence history since T2DM diagnosis							
	LTPA	*Diet*	*Meds*	*LTPA*	*Diet*	*Meds*	
Period 1 Adherence	✓	×	×	✓	×	×	
Period 2 Adherence	×	✓	✓	×	×	×	
Differences in individual outcomes							
Consumption *(units)*	32,386.88			33,116.44			**729.56**
Leisure *(hours)*	4,232.50			4,353.06			**120.56**
HRQoL	0.7826			0.7616			**-0.021**
Utility *(utils)*	9,162.98			9,144.78			**-18.2**
LPT *(hours)*	1,060.00			1,304.44			**244.44**
Probability of death	0.0479			0.0743			**0.0264**
PV of next period's value function *(utils)*	61,677.57			48,910.61			**-12,766.96**

The differences in future outcomes depicted in Table 21 are pronounced. Despite enjoying more consumption and more leisure, the individual actually anticipates *less* utility if he chooses not to properly manage his condition at age 60, as the comparatively rapid progression of T2DM and its complications will detract from the HRQoL he could otherwise experience. In addition

❖ just over two-thirds of the time the individual expects to gain from limiting allocation of time to meal preparation would be lost to illness anyway;

- the decision to eschew LTPA, healthy eating habits and/or pharmacotherapy is associated with a 55.1% increase in the probability of all-cause mortality between ages 70 and 71;

- and, the large difference in the present value of the expectation over the subsequent period's value function suggests recognition that the failure to invest in health will continue to negatively impact both enjoyment and (statistically speaking) duration of life.

Full circle

Table 22 summarizes the present value of the expected rewards attached to each choice the individual can make:

Table 22: Calculating the expectation over next period's value functions for every possible course of action, 60-year-old decision-maker (Caucasian male) with T2DM (duration—9 years)

Work hours	Adherence			Maximum achievable reward	$\delta\Sigma pV_{t+1}$	Value function (Year 0)
	LTPA	Diet	Medication			
Full-time	Adhere	Adhere	Adhere	6,238.24	75,512.52	81,750.76
Full-time	**Don't adhere**	**Adhere**	**Adhere**	**6,393.94**	**80,302.08**	**86,696.02**
Full-time	Adhere	Don't adhere	Adhere	6,361.06	78,432.88	84,793.94
Full-time	Don't adhere	Don't adhere	Adhere	6,500.30	75,397.39	81,897.70
Full-time	Adhere	Adhere	Don't adhere	6,571.62	71,131.73	77,703.35
Full-time	Don't adhere	Adhere	Don't adhere	6,735.64	74,623.33	81,358.96
Full-time	Adhere	Don't adhere	Don't adhere	6,733.47	72,568.97	79,302.44
Full-time	Don't adhere	Don't adhere	Don't adhere	6,880.87	69,851.89	76,732.76
Part-time	Adhere	Adhere	Adhere	4,629.15	75,512.52	80,141.67
Part-time	Don't adhere	Adhere	Adhere	4,716.35	80,302.08	85,018.43

Table 22: Calculating the expectation over next period's value functions for every possible course of action, 60-year-old decision-maker (Caucasian male) with T2DM (duration—9 years)						
Work hours	**Adherence**			**Maximum achievable reward**	$\delta\Sigma pV_{t+1}$	**Value function (Year 0)**
	LTPA	**Diet**	**Medication**			
Part-time	Adhere	Don't adhere	Adhere	4,312.44	78,432.88	82,745.32
Part-time	Don't adhere	Don't adhere	Adhere	4,385.90	75,397.39	79,783.29
Part-time	Adhere	Adhere	Don't adhere	4,876.35	71,131.73	76,008.08
Part-time	Don't adhere	Adhere	Don't adhere	4,968.21	74,623.33	79,591.53
Part-time	Adhere	Don't adhere	Don't adhere	4,604.10	72,568.97	77,173.08
Part-time	Don't adhere	Don't adhere	Don't adhere	4,682.53	69,851.89	74,534.42

Examination of the values in the final column of the table indicates that the optimal policy for a 60-year-old decision-maker (Caucasian male) who has lived with T2DM for 9 years is to adhere with healthy eating habits and prescribed medications—but not with regular physical activity—both in the year of diagnosis and every year thereafter. The value function for this individual is 86,696.02 *utils* which, by definition, is the highest level of well-being the individual can hope to achieve, given his state when he must make his decision.

I conclude with the following observations:

❖ That the value function does not significantly vary with the extent of the patient's participation in the labour market simply reflects the intent to make the same decisions going forward. In particular, the optimal policy directs the individual to work full time next period, irrespective of the number of hours they work now.

- While it is by no means self-evident from Table 22, the disinclination to adhere to LTPA in addition to healthy eating habits and pharmacotherapy is driven not only by the relative reduction in leisure this would entail, but also by the parameters of the UKPDS-OM2 risk equations, according to which underweight individuals (i.e., BMI < 18.5 kg/m^2) who have had T2DM for many years are under some circumstances at higher risk of all-cause mortality than their normal-weight or overweight peers (Hayes et al., 2013a, p. 1928; Hayes, Leal, Gray, Holman, & Clarke, 2013b). I return to this point in Section 3.2 in Chapter 4 below.

4.3.3 Example #3

In the final worked example, I consider the optimization problem encountered by a healthy 30-year old woman of Afro-Caribbean ancestry who is unemployed when their decision is made (i.e., Year 0). For the purposes of this discussion, I assume the individual possesses a postsecondary certificate or diploma below the bachelor level. As in the previous example, I take next period's (i.e., Year 1's) value functions as given, focusing primarily on the calculation of within-period rewards; however, I also use this opportunity to illustrate how healthy decision-makers form expectations concerning future health outcomes, and how this influences their choices in the present.

Table 23 lists all states the decision-maker may experience in Year 1, given their current circumstances; as shown, since they are currently healthy such individuals will not yet have had an opportunity to accumulate an adherence history:

Table 23: Achievable Year 1 states, healthy 30-year-old decision-maker (Afro-Caribbean female), unemployed

Health state	Employment state	Adherence: LTPA		Adherence: Diet		Adherence: Medication	
		Period 1 (Years 0-9)	Period 2 (Years 10+)	Period 1 (Years 0-9)	Period 2 (Years 10+)	Period 1 (Years 0-9)	Period 2 (Years 10+)
Healthy	Employed	N/A	N/A	N/A	N/A	N/A	N/A
Healthy	Unemployed	N/A	N/A	N/A	N/A	N/A	N/A
T2DM	Employed	N/A	N/A	N/A	N/A	N/A	N/A
T2DM	Unemployed	N/A	N/A	N/A	N/A	N/A	N/A
Dead	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Because the model assumes pharmacotherapy is initiated only upon diagnosis with T2DM (see Section 2.3.3 above), the individual's choice set is limited to adhering or not adhering to regular physical activity and/or to healthy eating habits. Below, I demonstrate the calculation of the within-period reward for an individual who has chosen to adopt both behaviours; I then compare the result with outcomes the individual realizes upon making other choices.

Estimating consumption

With reference, once again, to Equation (16), consumption is the difference between household income and the sum of income deductions (the sum of provincial and federal taxes, CPP/EI contributions, personal savings, and productivity losses) and health-related expenditures:

4) *Household income—denoted by Equation (16a).* The individual is unemployed during the decision epoch under consideration. Since the model does not at present incorporate EI programming, I assume she subsists on EIA while searching for work. Given the provincial and federal benefits for General Assistance Recipients prevailing as of July 1st, 2017 (see page 117 in Section 3.5.1), the individual's annual income is assumed to be $9,672.

5) *Deductions from income—denoted by Equation (16b).* EIA payments are considered non-taxable income, and, being unemployed, the individual does not make CPP or EI contributions. Moreover, unemployed individuals are not subject to the requirement to set aside a proportion of their EIA payments for retirement and by assumption, people who are healthy do not accrue LPT. In summary, therefore, this individual does not experience any deductions from income.

6) *Household consumption—denoted by Equation (16c).* In this example I have assumed compliance with LTPA and healthy eating habits. LTPA does not involve a financial outlay (see page 119 in Section 3.5.1), but for

a female of Afro-Caribbean extraction in the 25-44 age range, the methodology outlined in Appendix B yields an estimated annual dietary cost of $3,164.41 (see Table 8 on page 129). Finally, the assumption that pharmacotherapy is initiated only upon a T2DM diagnosis implies no medication expenditures for healthy individuals. Household expenses are therefore as follows:

$$
\begin{aligned}
HealthExp_t &= \left[p_{LTPA}^{DA} + \left(\Delta\, p_{LTPA}^{DA \to A} \times LTPA_t \right) \right] + \left[p_{Diet}^{DA} + \left(\Delta\, p_{Diet}^{DA \to A} \times Diet_t \right) \right] \\
&\quad + \xcancel{\left[p_{Meds}^{DA} + \left(\Delta\, p_{Meds}^{DA \to A} \times Meds_t \right) \right]} \\
&= \left[\$0.00 + \left(\$0.00 \times 1 \right) \right] + \left[\$5{,}123.37 + \left(-\$1{,}958.96 \times 1 \right) \right] \\
&= \$0.00 + \$3{,}164.41 = \$3{,}164.41
\end{aligned}
$$

Since the model assumes the per-unit price of consumption (i.e., p^c) to be one dollar, by default, final consumption is as follows:

$$
\begin{aligned}
& p^c c_t = Y_t - Deduct_t - HealthExp_t \Rightarrow c_t = \left(Y_t - Deduct_t - HealthExp_t \right) / p^c \\
& c_t = \left(\$9{,}672.00 - \$0.00 - \$3{,}164.41 \right) / \$1.00 = \$6{,}507.59
\end{aligned}
$$

Estimating leisure

With reference, once again, to Equation (17), the time for leisure is given by the difference between the total time available, and time allocated on a discretionary or non-discretionary basis to a range of possible activities:

$$\ell \quad {}_t^{NDisc} - T_t^{Disc}$$

$$1 \quad 2 \quad 3$$

4) There is a total of 8,760 hours in each year.

5) *Non-discretionary time use—denoted by Equation* (17a). Non-discretionary uses of time include those the individual must allocate to sleep, labour market (i.e., job search) and other activities, as well as LPT attributable to illness.

    a. *Sleep.* As in the last two examples, the model assumes Canadians spend about one-third of each day sleeping (i.e., 2,920 hours per year) (page 131).

    b. *LPT.* Since the individual is healthy, she loses no productive time to illness.

    c. *Labour market activities.* Although the individual is currently unemployed, we assume she is compelled to allocate time to searching for a new job, in keeping with the "work expectation" woven into the design of Manitoba's EIA Program (Province of Manitoba Department of Families, 2017a). I assume the individual allocates 9.5 hours per week to this activity, or 494 hours per year (see page 133 for rationale).

d. *Other non-discretionary activities.* While individuals are under no obligation to commit any time to LTPA or self-administering medications (as noted, this decision-maker has chosen to adhere to the former, and the latter does not apply to this situation), the model assumes even those deciding not to adhere to healthy eating habits must allocate at least 30 minutes per day (182.5 hours per year) to meal preparation (see page 134).

In summary, non-discretionary time use is calculated as follows:

$$
\begin{aligned}
T_t^{NDisc} &= T_{Sleep} + T_{Sick} + \left(T_{LTPA}^{DA} + T_{Diet}^{DA} + \cancel{T_{Meds}^{DA}}\right) \\
&\quad + LFS_t \times \left[Emp_t \times T_W^{PT} + \left(1 - Emp_t\right) \times T_{Search}\right] \\
&= 2{,}920.00 + 0.00 + \left(182.50 + 0.00\right) + 1 \times \left[0 \times 1{,}000.00 + 1 \times 494.00\right] \\
&= 2{,}920.00 + 182.50 + 494.00 = 3{,}596.50
\end{aligned}
$$

6) *Discretionary time use—denoted by Equation* (17b). Discretionary uses of time include work and participation in health-promoting activities:

a. The individual has, in this instance, chosen to participate in LTPA, and engage in healthy eating habits; as already noted, the model assumes physicians typically do not prescribe medications used to treat T2DM and/or its complications to healthy individuals. but that LTPA and healthy eating habits necessitate consume 130 and 365.00 hours each year, respectively, above and beyond the minimum requirement (page 136).

$$\begin{aligned} T_t^{Disc} &= LFS_t \times \left[Emp_t \times \left(\Delta T_W^{PT \to FT} \times FT_t \right) \right] + \left(\Delta T_{LTPA}^{DA \to A} \times LTPA_t \right) \\ &\quad + \left(\Delta T_{Diet}^{DA \to A} \times Diet_t \right) + \xcancel{\left(\Delta T_{Meds}^{DA \to A} \times Meds_t \right)} \\ &= 1 \times \left[0 \times \left(1,000.00 \times 1 \right) \right] + \left(130.00 \times 1 \right) + \left(365.00 \times 1 \right) \\ &= 0.00 + 130.00 + 365.00 = 495.00 \end{aligned}$$

Time available for leisure is then as follows:

$$\ell \qquad {}_t^{\neg NDisc} - T_t^{Disc} = 8,760.00 - 3,596.50 - 495.50 = 4,668.00$$

HRQoL

The model assumes HRQoL is equal to one for healthy individuals (see Section 3.4.4 above).

Calculating utility

The above calculations furnish the model with the elements necessary to estimate the within-period reward, excepting the elasticity of substitution, ρ, and the distribution parameter, α—which, as noted in Sections 3.4.2 and 3.4.3, are set by default to 0 and 0.5, respectively. This enables me to apply Equation (14) to calculate the individual's utility, noting, once again, that although the CES function ceases to be well-defined at $\rho = 0$, it approaches the Cobb-Douglas function in the limit:

$$u_t = f(h_t) \times \left[\alpha c_t^{\rho} + (1-\alpha)\ell \right.^{1} \qquad \ell$$
$$= 1.00 \times (6{,}507.59)^{0.5} (4{,}668.00)^{0.5} = 5{,}511.87$$

Similar results for the three other courses of action open to the decision-maker (i.e., adhering to LTPA but not healthy eating, adhering to healthy eating but not LTPA, and not investing in health in either way) are presented in Table 25 below.

Extending the exercise

Table 24 illustrates the calculation of the present value of the expectation over next period's reward function for every viable choice within their action space:

Table 24: Calculating the expectation over next period's value functions for every possible course of action, healthy 30-year-old decision-maker (Afro-Caribbean female), unemployed

State		LTPA	Adhere		Adhere		Don't adhere		Don't adhere	
		Diet	Adhere		Don't adhere		Adhere		Don't adhere	
Health	Empl.	V_{t+1}	Prob.	$p \cdot V_{t+1}$	Prob.	$p \cdot V_{t+1}$	Prob.	$p \cdot V_{t+1}$	Prob.	$p \cdot V_{t+1}$
Healthy	E	170,961	0.6365	108,810	0.6365	108,810	0.6365	108,810	0.6023	102,965
Healthy	U	166,251	0.3579	59,497	0.3579	59,497	0.3579	59,497	0.3387	56,301
T2DM	E	129,531	0.0034	435	0.0034	435	0.0034	435	0.0375	4,863

Table 24: Calculating the expectation over next period's value functions for every possible course of action, healthy 30-year-old decision-maker (Afro-Caribbean female), unemployed

State		**LTPA**	**Adhere**		**Adhere**		**Don't adhere**		**Don't adhere**	
		Diet	**Adhere**		**Don't adhere**		**Adhere**		**Don't adhere**	
T2DM	U	125,948	0.0019	238	0.0019	238	0.0019	238	0.0211	2,659
Dead	N/A	0	0.0004	0	0.0004	0	0.0004	0	0.0004	0
Total (*$\delta\sum p \cdot V_{t+1}$*)			**0.95 x 168,980 = 160,531**		**0.95 x 168,980 = 160,531**		**0.95 x 168,980 = 160,531**		**0.95 x 166,788 = 158,449**	

Because the individual could conceivably transition to any one of the same set of five states listed in the table in the coming period, one choice is preferable to any other in this context (momentarily setting aside the within-period reward, to which I return below) only because of its influence on the likelihood of transitioning to preferred states and of avoiding undesirable states. As shown, the present value of the expectation over next period's value functions does not depend on the combination of health-related activities to which they adhere, provided they engage in at least one; this is consistent with the results presented in Table 11 (pg. 161), which indicate that given the model's definition of adherence to LTPA and healthy eating habits (see Sections 2.3.1 and 2.3.2 above, respectively) and the parameters of the DPoRT 2.0 risk equations, engaging in either of these behaviours is sufficient to minimize the risk of developing T2DM. Uniform non-adherence is clearly sub-optimal relative to other courses of action.

Full circle

Table 25 summarizes the present value of the expected rewards attached to each choice the individual can make:

Table 25: Available choices for a healthy 30-year-old decision-maker (Afro-Caribbean female), unemployed					
Adherence: LTPA	**Adherence: Diet**	**Adherence: Medication**	**Maximum Achievable Reward**	$\boldsymbol{\delta \sum p \cdot V_{t+1}}$ **(Year 1)**	**Value function (Year 0)**
Adhere	Adhere	Not applicable	5,511.87	160,530.57	166,042.44
Adhere	Don't adhere	Not applicable	4,784.93	160,530.57	165,315.49
Don't adhere	**Adhere**	**Not applicable**	**5,588.08**	**160,530.57**	**166,118.65**
Don't adhere	Don't adhere	Not applicable	4,846.32	158,448.91	163,295.24

As shown, the optimal course of action involves adhering to healthy eating habits but not LTPA. To see why, I note that given that HRQoL is equal to one for healthy individuals and that the model assumes $\rho = 0$ and $\alpha = 0.50$ by default (see Sections 3.4.2 and 3.4.3, respectively), one can express the total differential of the utility function as follows—where I hold consumption and leisure constant at the levels enjoyed by an individual who adheres to both LTPA and healthy eating habits:

$$du_t\left(f\left(h_t\right), c_t, \ell \quad (\ )^{\alpha-1} \ \ell \quad (\ )^{\alpha} \ \ell$$

$$= 0.5 \times \left[\frac{6{,}507.58}{4{,}668.50}\right]^{-0.5} dc_t + (1-0.5) \times \left[\frac{6{,}507.58}{4{,}668.50}\right]^{0.5} d\ell$$

$$= 0.4235 \times dc_t + 0.5903 \times d\ell$$

Upon substituting in for dc_t and $d\ell_t$ the differences between these base levels of consumption and leisure and those corresponding to other combinations of health-related behaviours (and acknowledging that any results emerging from the use of the expression are merely approximations), one finds that whereas eschewing regular physical activity clearly increases the within-period reward by allowing more time for additional leisure (130 hours per year) without impacting the decision-maker's risk of developing T2DM. By contrast, if the individual chooses not to sustain healthy eating habits but remains physically active, utility losses resulting from reduced consumption more than outweigh any gains attributable to freeing up time (365 hours per year) that would otherwise have been allocated to meal preparation.[29]

4.4 Summary

Approaching the dynamic stochastic optimization problem analytically suggests the decision-maker should orient their activities such that at the margin, they will derive the same benefit from their last dollar of income irrespective of whether they spend it on consumption or leisure; in line with Zweifel et al. (2009), they

---

29 The results presented on page 106 in Section 3.5.1 suggest healthy eating may be more economical in some circumstances.

will be ambivalent about committing resources to consumption or leisure today or to increasing the present value of expected future welfare by reducing the likelihood of illness (i.e., by investing in health); and, they should be able to achieve the same level of risk reduction irrespective of how they deploy any additional resources allocated to sustaining or recovering health.

In practice, however, the discrete nature of the action space implies we will virtually never observe choices that satisfy these conditions and, indeed, the decision model is not amenable to solution through the application of analytical techniques—although we do expect the decision-maker to strive as close to the analytical optimum as their circumstances allow. One can conceptualize optimization under the numerical approach as the process of making pairwise comparisons between possible courses of action by contrasting the sum of current and expected future rewards and selecting the most highly ranked option.

In addition, the following predictions concerning the solution to the dynamic stochastic optimization problem emerge from an assessment of the functional form and parameters chosen for the reward function:

- ❖ In general, as α increases the bundle chosen by the individual will consist of relatively more consumption, whereas when α declines, the bundle will shift in favour of leisure. Moreover:

- With $\rho = 0$, decision-makers should attempt to arrange consumption and leisure so as to equate the budget share for each item with α (though with reference to the above discussion, they are unlikely to succeed), and demanded for leisure or supply of labour should be relatively insensitive to changes in either the prevailing wage or the price of consumption.

- With $\rho \neq 0$ the response to any change will depend on the degree of substitutability or complementarity between consumption and leisure.

- With reference to the worked examples (particularly Example #3), health-related decision-making will be linked to an individual's participation in the labour market:

    - Individuals who dedicate significant amounts of their time to generating employment income may seek to maximize well-being by making health investments that involve few or no time requirements.

    - Individuals who are unemployed or retired may prefer investments that conserve income and exploit the abundance of leisure at their disposal.

- One of the central objectives of this research is to study the circumstances under which people will forego consumption and leisure in the present in return for better chances of improved health outcomes (and, by extension, all the benefits with which this is associated) in the future. The larger is the discount factor, δ, the greater should be the decision-maker's willingness to make short-term sacrifices in service of health; by contrast, lower values of δ reflect "impatience" on the individual's behalf, and may be accompanied by disinclination to engage in regular physical activity or healthy eating habits, or to adhere to prescribed courses of pharmacotherapy.

- Although the reward function is characterized by negative state dependence, but this should not directly influence how people allocate their time or income because HRQoL reductions impact the enjoyment of consumption and leisure to the same degree.

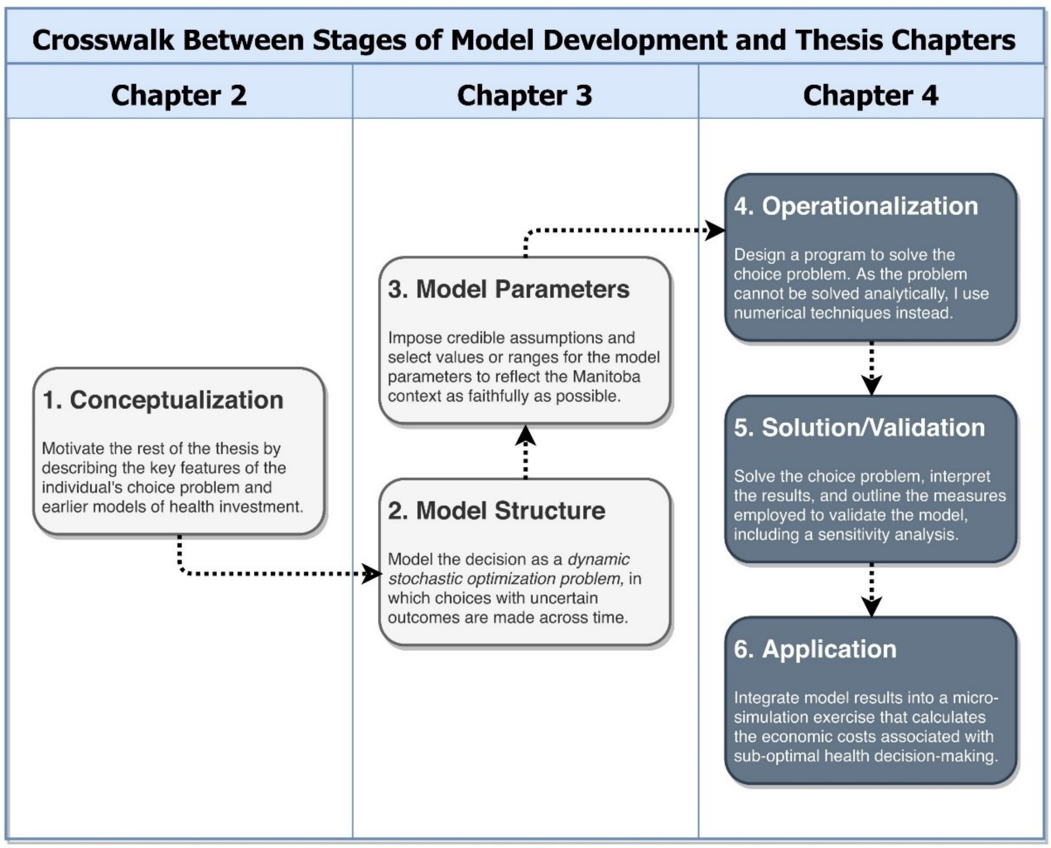
5. CONCLUSION

This chapter documents the development of a dynamic, stochastic model of health-related decision-making intended to contribute to our understanding of optimizing behaviour in the context of the risks posed by chronic diseases such as T2DM. The next chapter turns to a discussion of the implementation of the model and a demonstration of its policy applications.

Chapter 4: MODEL IMPLEMENTATION

1. INTRODUCTION

With reference to the development process presented in Chapter 1 (reproduced below, highlighting the appropriate components), this chapter documents the decision model's operationalization, solution, validation and application:



As shown in the figure, this chapter documents the following activities:

- *Operationalization* (Section 2 and Appendix E). Section 2 describes the model's operationalization as an integrated collection of programs written in R, MATLAB and Excel VBA, which is freely available to researchers through MSpace. Appendix E, meanwhile, serves as a user guide (also available through MSpace) that walks the reader through the sequence of steps required to solve the dynamic optimization problem.

- *Solution/Validation* (Sections 3 and 4, respectively). Whereas Chapter 3 (page 182) described the numerical technique (i.e., backward induction) employed to solve the decision problem, Section 3 focuses on interpreting the results. Section 4, meanwhile, outlines measures in place to ensure the decision model is free from error and that the values of the parameters driving my results are appropriate. As an element of the validation process, I investigate the sensitivity of model results to the values of several key parameters.

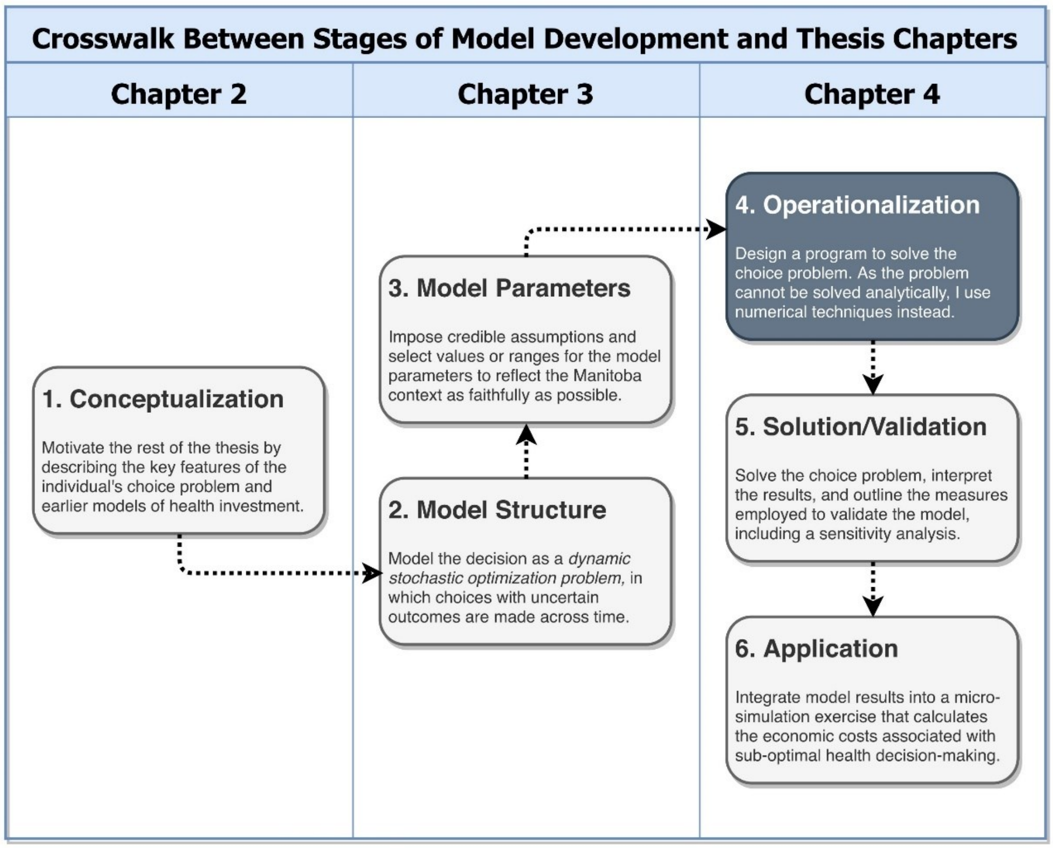
- *Application* (Section 5). The decision model was originally designed as a policy tool intended to study the implications of optimal health-related decision-making in terms of economic and health outcomes for Manitobans. Section 5 illustrates a specific application of the model, namely calculation of indirect economic costs (i.e., productivity losses) associated with optimizing behaviour within a cohort of Manitobans who were 25 years of age on June

1st, 2017, as compared with complete adherence to regular physical activity, healthy eating habits, and/or pharmacotherapy; complete non-adherence, and; complete non-adherence while healthy, transitioning to complete adherence upon diagnosis with T2DM.

Section 6 concludes with a discussion of the model's other potential applications, as well as an assessment of its current limitations and perceived opportunities for improvement and extension.

2. OPERATIONALIZING THE DECISION MODEL

This section briefly describes the implementation of the model framework described in Chapter 3, deferring a more detailed discussion to Appendix E:



The decision model consists of an integrated collection of programs developed by the author in R, MATLAB and Excel VBA. The model comes packaged with, or is programmed to acquire all materials required to replicate the findings presented in this chapter, except

- a selection of user-developed packages (listed in Table 39 in Appendix E), which extend the functionality of the R software environment;

- the MDPSolve Toolbox, a utility freely available from Paul Fackler's (2014) website which includes a function that implements the backward induction algorithm in MATLAB;

- the United Kingdom Prospective Diabetes Study Outcomes Model v2 (UKPDS-OM2), which is licensed free of charge to academic organizations by the University of Oxford (Diabetes Trials Unit, 2018), and;

- the 2011 National Household Survey (NHS) and 2011 Survey of Labour and Income Dynamics (SLID) Public Use Microdata Files (PUMFs).

The model first gathers, processes, and ultimately compiles raw data from a wide range of sources referenced in Chapter 3. The results of this exercise serve as inputs into the dynamic optimization problem, which is then solved through backward induction algorithm by employing functions accompanying the above-mentioned MDPSolve Toolbox.

Once solved, the model outputs the decision-maker's optimal policy and value function. Although these may be of interest for their own sake, they can also be used to drive microsimulation exercises, examples of which are presented in

Section 5 below, that illustrate how the projected prevalence and incidence of T2DM, and direct and/or indirect losses attributable to the condition, may vary in populations with prespecified characteristics in different user-defined scenarios.

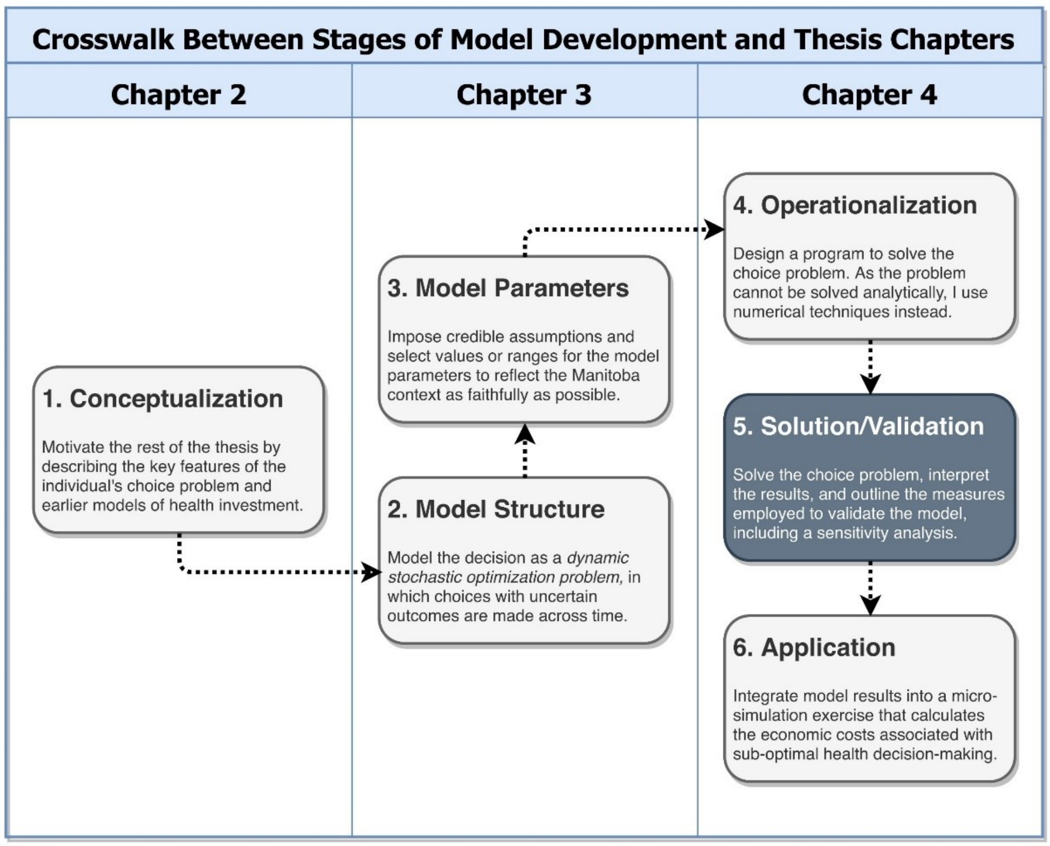
The decision model is stored in a compressed file archive (ZIP format) at the following location on MSpace, an online repository for intellectual output created by researchers associated with the University of Manitoba (2018):

<LINK TO ZIP FILE HERE>

For the sake of brevity, I now turn to summarizing and interpreting model results. However, for those readers interested in replicating these results or applying the model to serve their own ends, a comprehensive discussion of its structure is presented in Appendix E, along with step-by-step instructions that should equip researchers to successfully deploy the decision model, set up and solve the dynamic optimization problem, implement sensitivity analyses, and design and carry out microsimulation exercises similar to those described in Section 5 below. I also refer the reader to an online demonstration (https://youtu.be/1u50_bkacx0) intended to fulfill many of these same objectives.

3. INTERPRETING MODEL RESULTS

This section presents and interprets results from the decision model, while the next focuses on validating its structure and the values of selected parameters:



3.1 Interpretive principles

This section describes how to interpret the outputs generated by the decision model, with reference to my own results. Although the user's results may differ from those presented here (e.g., due to updated parameter values or other user-introduced modifications), the discussion should offer useful guidance to those attempting to apply the model for their own purposes.

3.1.1 Optimal policy

The optimal policy is the sequence of actions that maximizes the value function. That is, given his or her state at a moment in time, the optimal policy describes what the decision-maker should do now to achieve the largest possible sum of current and expected future well-being. Expected future well-being, in turn, is the weighted sum of the value functions for each state the individual could occupy next period, with the probabilities of transitioning to those states acting as the weights. This discussion implies decision-makers will select a course of action over others for at least one of the following reasons:

- Other things equal, it generates more utility in this decision epoch, by enabling the individual to enjoy more consumption and/or leisure. It is important to note that although HRQoL also influences current utility it does not depend on current choices, being determined solely by the individual's state of health when making their decision.

- ❖ Other things equal, it increases the probability of desirable state transitions and/or reduces the likelihood of undesirable ones. That is, people are motivated to invest in health because they realize this can prevent or delay the emergence of T2DM and forestall death. The desirability of a state transition is determined by its associated value function, which reflects the individual's appraisal of the present value of the stream of expected utilities they anticipate they will enjoy if they make optimal choices from next period onward. The recursive nature of the optimization problem means next period's value functions, in turn, reflect the outcome of a sequence of choices driven by the two factors just described.

In the Zweifel, Breyer, and Kifmann ("ZBK") model (2009) serving as the inspiration for this research, the optimality conditions direct the individual to invest in health up until the point where the immediate loss of utility this entails (since investment diminishes current consumption possibilities) is exactly offset by the present value of the gain in utility expected to result from decreasing the likelihood of material reductions in future consumption due to illness (see Equation (27) on page 189).

A simpler two-period version of the decision model that is amenable to solution through the application of analytical techniques and that introduces leisure and an arbitrary number of health interventions reaches a similar conclusion (Equation (26) on page 188). However, it also adds the standard result that each good should yield the same level of marginal utility per dollar in each period, and the novel but intuitive result that the individual should commit to each health-promoting activity so as to equalize the incremental risk reduction achievable through the last dollar of health investment (Equations (24) and (25) on page 187).[30]

While these intuitions are valuable, the discussion in Section 4.2.3 in Chapter 3 emphasized that because the decision model's state and action spaces are discrete in nature, it is not amenable to solution through the use of analytic techniques. Rather, one can instead conceptualize the solution approach as the process of making a finite series of pairwise comparisons between possible courses of action by contrasting the sum of current and expected future rewards and selecting the most highly-ranked option.[31] This suggests the individual has no assurance they will be able to precisely satisfy the optimality conditions derived by applying analytic techniques.

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30 There is no analogous condition in the ZBK model, since the state-dependent nature of production is such that only a single input is efficacious in recovering or sustaining health at any time.

31 As noted in Chapter 3, the backward induction algorithm selects the largest value from among all possible alternatives. Strictly speaking, comparisons would only be pairwise if there were two courses of action to choose from. That said, with enough pairwise comparisons one would ultimately obtain the desired result, irrespective of the number of available choices.

Further to the above, I note that given the baseline parameter values selected for the decision model

- participating in LTPA requires a modest investment of time (130 hours/year), but not money;
- adhering to pharmacotherapy (initiated upon diagnosis with T2DM) does not require time be allocated for self-administration, but is associated with a modest financial outlay that increases as T2DM progresses (see Appendix C, noting the values are individual-specific, because Pharmacare deductibles are tied to one's current state and personal attributes), particularly if the disease is not well-managed;
- while less costly than eating unhealthfully (see Table 8 on page 129 in Chapter 3), adhering to healthy eating habits requires substantially more time be allocated to meal preparation (547.5 hours/year versus 182.5 hours/year);

With reference to the discussion in Section 4.1 in Chapter 3 and the worked example in Section 4.3.3, optimizers will, other things equal, be more inclined to make investments in health that entail foregoing consumption of goods they value least, given their personal characteristics and circumstances (i.e., as represented by the state they occupy).[32] For example, people who place a premium on leisure and/or for whom time is scarce—most notably, those who are employed and wish to maximize their ability to generate income in the labour market—would be more likely to commit to health-promoting activities that require relatively little time, such as LTPA and, where applicable, pharmacotherapy.

The opposite should be true of those who place a premium on consumption or are income-constrained, as is true of those subsisting on EIA or retirees who have exhausted their accumulated assets. Such individuals may favour adoption of healthy eating habits over other health-promoting activities, since the costing exercise undertaken as part of this research suggests a high-quality diet may in some circumstances impose less of a financial burden than an unhealthier alternative (see Table 8 on page 129), even if it requires a larger temporal investment. Adherence with pharmacotherapy among such individuals is more difficult to predict, since an individual's drug expenditures are increasingly likely

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32 This is **not** intended to imply preferences themselves vary across individuals—the model assumes everyone shares a common utility function—but rather to highlight the observation that a person's attributes and circumstances can determine their marginal valuations of consumption and leisure by influencing their opportunities to enjoy each. This, in turn, can result in different observed patterns of decision-making even among individuals with identical preferences.

to exceed their Pharmacare deductible as household income declines, and individuals relying on EIA need not pay even the deductible.

Finally, that health-related decisions by individuals diagnosed with T2DM can only be taken at predefined points in time (i.e., upon diagnosis, and again nine years later) means economic agents are bound to choices made during earlier decision epochs. Recognizing this, they will weigh their options carefully to avoid committing to courses of action they anticipate they might come to regret. This is perhaps best exemplified by the decision to adhere to pharmacotherapy upon diagnosis with T2DM. Since EIA recipients are exempt from paying Pharmacare deductibles, they have a strong incentive to adhere to prescribed medications; they must however account for the possibility they will recover employment prior to the next decision epoch, in which case the exemption is lost. As such, if the deductible deters the individual from taking prescribed medications when employed, they are unlikely to commit to long-term adherence when unemployed.

Table 26 summarizes the optimal policy for a specific reference case, namely a female of Asian-Indian descent with a post-secondary degree at the Bachelor’s level or above. We focus here simply on highlighting some of the key features of the optimal policy, deferring their interpretation to Section 3.2.

It is important to recognize that Table 26 presents a subset of the full policy, which, by definition, prescribes a course of action for every state the decision-maker might occupy—including every age (as opposed to a single observation for each decade of life), every year elapsing since diagnosis with T2DM,[33] and every possible combination of prior lifestyle behaviours (as opposed to full adherence or non-adherence during the decade immediately following diagnosis with T2DM):

Table 26: Characteristics of the optimal policy for individuals of varying age, and health and employment status *(Female; Asian-Indian; Bachelor's degree or above)*

Age	Employment Status	Healthy			Newly Diagnosed (Year 0)				T2DM, Poor Adherence (Year 9)				T2DM, Good Adherence (Year 9)			
		LTPA	**Diet**	**LMP**	**LTPA**	**Diet**	**Meds**	**LMP**	**LTPA**	**Diet**	**Meds**	**LMP**	**LTPA**	**Diet**	**Meds**	**LMP**
25	E	DA	DA	FT												
25	U	DA	A	FT												
35	E	A	DA	FT	A	DA	A	FT								
35	U	DA	A	FT	DA	A	A	FT								
45	E	A	DA	FT	A	DA	A	FT	A	DA	DA	FT	DA	A	A	FT
45	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
55	E	A	DA	FT	A	DA	A	FT	A	DA	DA	FT	A	DA	A	FT
55	U	DA	A	FT	DA	A	A	FT	DA	A	DA	FT	DA	A	A	FT
65	E	A	DA	FT	DA	A	A	FT	DA	A	A	RT	DA	A	A	FT
65	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
75	E	DA	A	RT	DA	A	A	RT	DA	A	DA	RT	DA	A	A	RT

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[33] Table 26 focuses on optimal choices upon diagnosis and nine years thereafter, since the decision model assumes health-related decisions can only be taken at these times.

Table 26: Characteristics of the optimal policy for individuals of varying age, and health and employment status *(Female; Asian-Indian; Bachelor's degree or above)*																
Age	**Employment Status**	**Healthy**			**Newly Diagnosed (Year 0)**				**T2DM, Poor Adherence (Year 9)**				**T2DM, Good Adherence (Year 9)**			
		LTPA	**Diet**	**LMP**	**LTPA**	**Diet**	**Meds**	**LMP**	**LTPA**	**Diet**	**Meds**	**LMP**	**LTPA**	**Diet**	**Meds**	**LMP**
75	U	DA	A	RT	DA	A	A	RT	DA	A	DA	RT	DA	A	A	RT
85	E	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	A	RT
85	U	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	A	RT
NOTE: E ≡ employed; U ≡ unemployed; LTPA ≡ leisure-time physical activity; A ≡ adherent; DA ≡ non-adherent; LMP ≡ labour market participation; FT ≡ full-time; PT ≡ part-time; RT ≡ retire																

As shown, the optimal policy indicates Asian-Indian females with advanced levels of education ought to do the following:

- ❖ If they are healthy, they should adhere to LTPA but not healthy eating if employed and do the opposite if unemployed. Once retired, they should adhere only to healthy eating habits.

- ❖ If recently diagnosed with T2DM, moreover, the optimal policy directs them to do essentially the same thing. In addition, they should adhere to prescribed courses of pharmacotherapy unless diagnosed late in life.

- ❖ If the individual has lived with T2DM for many years and did not actively manage their condition in the past, the optimal course of action is like the one selected by those recently diagnosed with the condition, except that adherence to pharmacotherapy is much less consistent.

- ❖ If the individual has lived with T2DM for many years but has managed their condition well, they should generally continue to do so by adhering either to LTPA or healthy eating habits (typically not both together) and taking any medications prescribed by their physician.

- ❖ Individuals with T2DM will retire slightly sooner than their peers, particularly if they did not previously manage their condition well.

Comparison of Table 26 with optimal policies selected by individuals varying by gender, ethnicity and level of educational attainment (see Table 42 in Appendix F) suggests broad similarity in several respects:

- ❖ Individuals who are healthy will typically adhere to LTPA and/or healthy eating habits at nearly every point in their lives. If employed, they may engage in LTPA but not eat healthfully; if unemployed, by contrast, they may do the opposite. This pattern is most commonly observed among those with the highest levels of educational attainment.

- ❖ Individuals just diagnosed with T2DM will tend not to adhere to LTPA, excepting employed decision-makers with high levels of educational attainment (i.e., university certificate, diploma, or degree at bachelor level or above), and a subset of female retirees. Meanwhile, adherence to healthy eating habits is nearly uniform, again excepting well-educated individuals who sustain employment during their prime earning years. Compliance with medication varies by gender:

- Males will tend to adhere to pharmacotherapy unless diagnosed at advanced ages (i.e., 80+).

- Compared with males, adherence begins dropping off several years sooner in recently diagnosed female retirees. Younger women, by contrast, will typically comply with pharmacotherapy unless engaging in both regular physical activity and healthy eating habits.

- Individuals who have had T2DM for several years, irrespective of how they chose to manage their condition in the past, will tend to adhere to both healthy eating and prescribed courses of pharmacotherapy, but not regular physical activity. In addition:

    - For some individuals—particularly women in their 30s and 40s with high levels of educational attainment—I again observe a preference for LTPA among those who are working and for high-quality diets among those who are unemployed.

- Diabetics with a history of poor adherence to treatment will in some instances eschew LTPA and/or prescribed medications when their otherwise identical (but historically adherent) counterparts do not.

- Highly-educated women—but not men—will tend to retire a little sooner if they were historically non-adherent with treatment than otherwise.

3.1.2 Value function

The value function indicates the largest possible sum of the present values of expected within-period utility flows achievable from a person's current state, from now until the end of the period under consideration. Alternatively, it denotes the level of well-being an individual can anticipate enjoying over their lives by implementing the optimal policy.

Table 27 summarizes estimates of the value function for a specific reference case, namely a female of Asian-Indian descent with a post-secondary degree at the Bachelor's level or above (a worked example illustrating the mechanics behind these calculations is presented in Section 4.3 in Chapter 3 above). As with the discussion of the optimal policy, I focus here simply on highlighting noteworthy observations about these estimates, deferring their interpretation to Section 3.2.

I also reiterate that as with Table 26, Table 27 reports only a small subset of the results generated by the decision model, which are too expansive to present in the body of this thesis, even as an appendix; however, analysis of the information summarized below nonetheless captures many of the key insights emerging from the solution to the decision problem:

Table 27: Estimates of the value function for individuals of varying age, and health and employment status *(Female; Asian-Indian; Bachelor's degree or above)*

Age	Employment Status	Healthy	Newly Diagnosed (Year 0)	T2DM, Poor Adherence (Year 9)	T2DM, Good Adherence (Year 9)
25	Employed	212,492	NA	NA	NA
25	Unemployed	204,957	NA	NA	NA
35	Employed	218,173	160,701	NA	NA
35	Unemployed	208,308	152,333	NA	NA
45	Employed	207,144	154,377	136,678	148,074
45	Unemployed	197,266	146,174	130,095	141,104
55	Employed	193,468	141,770	130,735	141,145
55	Unemployed	181,268	131,791	122,131	132,405
65	Employed	170,594	123,630	111,228	121,742
65	Unemployed	169,472	123,276	111,228	121,312
75	Employed	123,690	93,685	77,786	86,992
75	Unemployed	123,690	93,685	77,786	86,992
85	Employed	60,473	46,608	37,559	44,131
85	Unemployed	60,473	46,608	37,559	44,131

NOTE: E ≡ employed; U ≡ unemployed

The following observations emerge from assessment of the results in Table 27:

❖ The value function increases in early adulthood but declines thereafter.

- ❖ The value function is usually larger for those who are employed than those who are not. However, the difference narrows considerably once a person reaches the standard age of retirement and disappears completely thereafter.

- ❖ Other things equal, a diagnosis of T2DM is associated with a significant reduction in the value function. Increased duration of T2DM is also associated with declines in the value function, but the magnitude of the reduction is significantly larger when the condition has been poorly managed.

In addition, comparison of Table 27 with value functions for individuals varying by gender, ethnicity and level of educational attainment (see Table 43 in Appendix F) suggests each set of value functions shares the two latter characteristics (the tendency for the value function to increase in early adulthood is more likely to be observed in those with higher levels of educational attainment). In addition, I observe the following:

- ❖ The value function invariably increases in an individual's level of educational attainment.

- ❖ Among individuals of a specific gender who have the same level of education, the value function is always larger for healthy individuals of Caucasian ancestry than those of Afro-Caribbean or Asian-Indian descent. This is not necessarily true of those who have already been diagnosed.

- At younger ages, the value function tends to be larger for males than for females with the same ethnicity and level of education, except for individuals with a Bachelor's degree or higher level of educational attainment, for whom the opposite is typically true. The relationship between the gender differential, age, and health and employment status appears to be complicated and few generalizations are possible—although it is nearly always true that the value function is larger for highly-educated women than their male counterparts.

3.2 Interpreting the results

The solution to the optimization problem indicates healthy individuals generally act to reduce their risk of T2DM by engaging either in regular physical activity or healthy eating habits. Examination of Table 27 reveals the rationale for this choice: other things equal, a T2DM diagnosis is associated with a sizable drop in expected lifetime well-being (i.e., the value function), which is attributable to an immediate and irreversible drop in HRQoL and higher susceptibility to diabetic complications that can further detract from quality of life, compromise one's ability to generate labour market income and engage in leisure, and increase the risk of mortality.[34]

That they do not adhere to both regular physical activity and healthy eating habits concurrently reflects the fact that there is a floor beyond which the risk cannot be further reduced. Since the same probability is achieved either way, the individual chooses the one which detracts least from their immediate well-being.

Employed individuals in the youngest age bracket often do not adhere to healthy eating habits and none (i.e., irrespective of employment status) adhere to LTPA. This reflects the assumption that the transition to T2DM typically would not take place in a single year, one implication of which is that youth enjoy a "grace period" during which actions do not have health-related consequences. For individuals aged 26+, the risks posed by T2DM are enough to motivate commitment to all preventive measures available to them.

The model indicates that other things equal, healthy individuals of Caucasian descent have greater expected lifetime wellbeing than individuals of Afro-Caribbean or Asian-Indian descent. This reflects the values of the parameters

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[34] The UKPDS-OM2 assigns an initial HRQoL score of 0.807 to individuals with T2DM, based on results obtained by Alva et al. (2014).

underpinning the Diabetes Population Risk Tool (DPoRT) 2.0 equations (Rosella et al., 2014), which dictate the annual probability of developing T2DM in the decision model, and which support the observation that individuals of non-Caucasian ancestry are typically at increased risk of T2DM, at least in part due to factors beyond their control (Public Health Agency of Canada, 2011a, p. 69).

Following diagnosis, however, the relationship between ethnicity and the value function is much more complex, with the magnitude of the latter being relatively larger for Caucasian decision-makers in some instances and for their Afro-Caribbean and Asian-Indian counterparts in others. Analysis of UKPDS-OM2 simulation results and its underlying risk equations suggest this is attributable to ethnic differences in susceptibility to some diabetic complications and differences in the likelihood of all-cause mortality. For instance, the equations indicate that compared to Caucasians, diabetic males of Asian-Indian extraction are at increased risk of their first myocardial infarction, while Afro-Caribbean patients of both genders are at reduced risk for myocardial infarction but increased risk for renal failure (Hayes et al., 2013a).

Choices among individuals recently diagnosed with T2DM vary widely. It is uncommon for such individuals to engage concurrently in regular physical activity, healthy eating habits, and compliance with prescribed medications, but they will generally adhere to at least two of these behaviours at any time. In general, and as intuition would suggest, this occurs because people perceive that the expected benefits of adhering to more of these behaviours do not merit the expected costs. However, it is more instructive to examine specific examples.

In some instances, prior to the standard age of retirement employed newly diagnosed T2DM patients are seen to adhere to LTPA but not diet, while those who are unemployed adhere to the latter but not the former. This occurs because the marginal utility derived from leisure is relatively high among the employed (allocating more time to work means less is available for other uses), while the marginal utility derived from consumption is relatively high among the unemployed (social assistance income is invariably lower than what a person can earn in the labour market, and the model assumes job search is generally less strenuous than actually working). Healthy eating habits are less costly to sustain but require a greater time commitment (see Section 3.1.1) than eating unhealthfully, so these are ideal for people with a lot of time but relatively little income. By contrast, low-quality diets that may require a greater financial outlay but involve devoting less time to meal preparation are appealing to those for whom time is at a premium.

Another factor drives disinclination to simultaneously engage in LTPA and healthy eating, particularly among individuals who have had T2DM for many years: adhering to both health-related behaviours concurrently runs the risk of experiencing underweight (i.e., BMI < 18.5 kg/m^2), which increases the likelihood of all-cause mortality for individuals who have a history of micro- or macrovascular complications but did not experience events in this year (Hayes et al., 2013a, p. 1928, 2013b). We do not observe this behaviour in healthy individuals, for whom mortality rates are based upon general life tables for Manitoba, which do not account for BMI. It is also uncommon among individuals newly diagnosed with T2DM, likely because they have not yet accumulated a history of diabetic complications.

As another example, analysis of the optimal policies suggests newly diagnosed female decision-makers often (though not always) choose not to comply with pharmacotherapy, especially when they have low levels of educational attainment or beyond the standard age of retirement. This would seem to be particularly counterintuitive for women who are unemployed during a given decision epoch, since EIA recipients are not required to pay Pharmacare premiums, but the phenomenon can be explained as follows:

- ❖ In the National Household Survey data serving as the basis for the household income figures incorporated into the model, women generally earn less in the labour market than men of the same age with similar levels of education. Thus, as in the previous example, we would expect women to exhibit a preference for health behaviours that enable them to conserve their earnings.

- ❖ Although adherence to pharmacotherapy is costless for individuals on social assistance, recipients only receive this benefit for as long as they are unemployed. Because the model restricts when health choices can be revisited, decisions made upon diagnosis involve a long-term financial commitment that may be unpalatable to people who expect their circumstances to change.

- ❖ Examination of the UKPDS-OM2 risk equations suggests that female gender is associated with reduced likelihood of several microvascular and macrovascular complications, as well as lower rates of mortality for those who have not yet experienced these. Females therefore appear to enjoy a degree of natural protection from diabetic complications, which may reduce the level of investment they need to limit exposure to the risks associated with their condition to acceptable levels.

I also observe a tendency for individuals with T2DM to suspend adherence to some health behaviours near the end of their lives if newly diagnosed with the condition or if otherwise presented with the opportunity to do so (i.e., after having had diabetes for 9 full years). These individuals perceive it is no longer rational to sustain health investments, since the individual does not anticipate living to see the implications of allowing these to lapse.

We conclude this discussion by explaining two fairly general observations regarding the value functions presented in Table 27 and Table 43, namely their tendency to increase in early adulthood before declining more or less continuously thereafter; and, the equivalence of value functions for employed and unemployed individuals after reaching the standard age of retirement:

- The tendency for the value function to decline with age reflects the fact that statistically speaking, each year of life lived implies fewer remaining years. Increases in the value function in early adulthood results from rapid wage growth a person typically enjoys as they accumulate experience and skills, which more than compensates for the value of the time already spent.

- Convergence of value functions for employed and unemployed individuals at or beyond the standard age of retirement age 65 occurs because the former typically do not defer the retirement decision for very long and will thereafter receive the same income as their unemployed counterparts (the model assumes people who are unemployed at age 65 or are subsequently terminated from their positions transition automatically to retirement).

3.3 Integrating model results with microsimulation

We can conceptualize the solution to the dynamic optimization problem as the outcome of a speculative exercise in which people are asked what they would do in various situations (i.e., the optimal policy) and how much well-being they would expect to enjoy over the remainder of their lives if they behaved in this way (i.e., the value function).

The decision model does **not** indicate what outcomes we might observe if people acted in accordance with their optimal policies. In contrast to decision analytic models commonly used to conduct economic evaluations of health interventions, it does not, for example, enable us to predict what the prevalence and incidence of T2DM might be if people behaved in a manner consistent with the solution to the dynamic optimization problem, or how much time and money they might spend in adhering to LTPA, healthy eating habits and/or pharmacotherapy.

It does, however, provide us with the inputs necessary to answer these types of questions. To see this, we note that discrete action/state Markov decision problems like this one specify the probability of transitioning from any state, to any other state, for every choice the individual could make. This means there are, in effect, 24 distinct transition probability matrices. It also implies that an individual's decision entails selecting which set of transition probabilities should govern the transition to a new state over the coming year.

By referencing the characteristics of the optimal policy, we can collapse all 24 transition probability matrices into a single *optimal transition matrix*. This can then serve as the foundation for microsimulation modelling exercises like those often used in health economic evaluations, as we illustrate in Section 5 below.

4. VALIDATING THE DECISION MODEL

This section describes the validation of the decision model. It outlines the measures employed to ensure the code is free from error. It then examines the extent to which the model's results are sensitive to assumptions about the values of several key parameters, including preferences over consumption and leisure; productivity decline attributable to aging; the relative costs of healthy and unhealthy eating habits; rates of time preference; and household savings.

4.1 Overview of validation measures

I introduced or availed myself of the following measures to promote the integrity of the code underlying the decision model and ensure the validity of its results:

- I explicitly documented the function of each script incorporated into the model. In addition, I thoroughly annotated and subdivided each script into sections to promote understanding of its underlying logic. The annotation also highlights where I had experienced challenges during model construction, enabling me to identify and address such issues more easily thereafter. I also engaged in a rudimentary form of version control by documenting the date and nature of significant changes to the code and preserving backups of earlier versions of each script, enabling me to revert to a prior version if modifications did not function as intended.

- The model includes several embedded checks and balances intended to flag issues for the user, including but not limited to several introduced by the author, such as the following:

    - The MDPSOLVE function incorporated into Paul Fackler's (2014) MDPSolve Toolbox halts implementation of the backward induction algorithm if the sum of transition probabilities associated with each initial state are not sufficiently close to one, or if the transition probability and reward matrices are non-conformable for multiplication.

- The UKPDS-OM2 contains several embedded validation measures to ensure input sheets have been appropriately populated before being used as the basis for simulation modelling exercises (University of Oxford Diabetes Trials Unit & Health Economics Research Centre, 2015, p. 24).

- Scripts developed to facilitate interpretation of model results alert the user to cases in which people desert health-related behaviors to which they had previously committed, which may reveal errors in the construction of the reward and/or transition probability matrices or in the solution of the optimization problem.

- Automation is a central tenet of my approach to validation, since the decision model involves a sizable volume and range of calculations, the manual execution of which would introduce an unacceptable risk of human error. Accordingly, the model relies heavily on the application of loop control statements (e.g., commands that stipulate carrying out an activity a prespecified number of times in sequence) and vectorization (i.e., commands that apply an operation to an entire array simultaneously) to carry out repetitive tasks, such as the following:

- As noted in Section E.4, the UKPDS-OM2 requires the user to prepare input sheets that specify the characteristics of initial risk factor values of the starting cohort, and that indicate how risk factor values evolve over time. Given the decision model's design, in the present context this entails populating 64 Excel workbooks with 70 years' worth of "observations" on 12 risk factors over a hypothetical patient cohort consisting of 414 people. The user can accomplish this with a single key stroke by executing the macro embedded in *UKPDS_Data_Template_V5.xlsm*.

- For the baseline analysis, the decision model relies on reward and transition probabilities for all combinations of gender, ethnicity, and education. The sensitivity analysis requires similar inputs for all user-specified values of the parameter of interest. Loop control statements incorporated into the scripts packaged with the model allow each operation to be completed through a single command.

- Examining the degree to which model results vary in response to changes in one or more parameters (i.e., sensitivity analysis), as we do in Section 4.2, performs double duty as a validation mechanism:

  - First, it enables the user to verify whether analytical results agree with expectations formulated from economic theory. If results do not align with expectations, this could imply the presence of errors in the code; alternatively, it may suggest the phenomena under investigation are more complicated or nuanced than previously recognized.

- Second, it supplies an opportunity to confirm the appropriateness of the default parameter values incorporated into the model.

- Finally, while not its central function, conducting microsimulation exercises with optimal policies derived from the solution to the DP problem, as I do in Section 5, can support the validation process by illustrating how decision-makers' choices actually translate into outcomes of interest. For instance, non-permissible health-state transitions (e.g., from T2DM back to normoglycemia, or from deceased to any other state) might suggest errors in constructing the transition probability matrix. As another example, predictions regarding T2DM incidence/prevalence or indirect economic losses that deviate significantly from observed values or predictions developed by others, may signal the presence of errors in the decision model or may suggest values or ranges for one or more key parameters are inappropriate.

4.2 Sensitivity analysis

As just noted, sensitivity analysis offers a valuable opportunity to validate the structure of the decision model while facilitating evaluation of the appropriateness of its constituent parts. For the purposes of this thesis, we consider the sensitivity of model results to the following five model components:

- The elasticity of substitution between consumption and leisure, as reflected in the value in the share incorporated into the modified constant elasticity of substitution (CES) equation that serves as the model's reward function.

- Preferences over consumption and leisure, as reflected in the distribution parameter of the modified CES utility function.

- The strength of the individual's preferences for current versus future consumption and leisure, as expressed in the value of the discount factor.

- The rate of age-related productivity decline beyond the standard age of retirement.

- The financial costs required to support unhealthy eating habits, expressed as a proportion of the default value.

4.2.1 Elasticity of substitution

This part of the sensitivity analysis examines how optimal policies and reward functions emerging from the solution to the dynamic optimization problem vary with the elasticity of substitution between consumption and leisure. I contrast three scenarios: weak separability (i.e., $\rho = 0, \sigma = 1$), strong complementarity (i.e., $\rho = -10, \sigma = 0.091$), and strong substitutability (i.e., $\rho = 1, \sigma = \infty$). In addition, I extend the analysis by studying how decision-making changes with the price of consumption within each scenario. Table 44 in Appendix G presents the results from this part of the sensitivity analysis.

I start with observations concerning changes in ρ at baseline prices, beginning with decisions concerning labour market activity and then delving into health-related choices. As already noted, when consumption and leisure are weakly separable, employed individuals typically elect to work full-time hours, and generally retire within a few years of the standard age of retirement. When they are complements, by contrast, people prefer working part-time hours and retire as early as the model permits (i.e., age 65), while when they are substitutes, people reliably work-full time hours and sustain their attachment to the labour force until well past the standard age of retirement. Differences in health-related behaviour across the three scenarios are summarized in Table 28:

Table 28: Health-related behaviour under varying assumptions concerning the elasticity of substitution			
Health state	**Complements ($\rho = -10$)**	**Baseline ($\rho = 0$)**	**Substitutes ($\rho = 1$)**
Healthy	Patterns of health investment resemble those observed when consumption and leisure are weakly separable.	Decision-makers engage in LTPA rather than eat healthfully, if employed—while adhering only to healthy eating habits after retirement.	Decision-makers always adhere to healthy eating habits while abstaining from regular physical activity.
Newly-diagnosed	Decision-makers always adhere to LTPA and pharmacotherapy.	Prior to retirement, health behaviour depends on employment status. It consists thereafter of a combination of healthy eating habits and pharmacotherapy—except, in the latter case, at advanced ages.	Decision-makers adhere to LTPA and healthy eating habits but not medication up to and including the standard age of retirement; behaviour thereafter is variable, but typically involves a high-quality diet and excludes adherence to prescribed medications.
Established T2DM	Decision-makers always adhere to LTPA and pharmacotherapy.	Health behaviour varies with an individual's attachment to the labour market. People are disinclined to comply with prescribed medications when T2DM management has historically been poor.	*Poor historical adherence.* Decision-makers will adhere only to healthy eating habits, altogether foregoing LTPA and pharmacotherapy. *Good historical adherence.* As above, except decision-makers also engage in regular physical activity until middle age.

When consumption and leisure are complements, they are enjoyed (in the extreme case) in fixed proportions, and the contribution of excess amounts of either is heavily discounted. In general, the action space in the decision model consists of bundles that are "consumption-heavy", which occurs because the number of hours available for leisure is almost invariably less than the amount of income (expressed in dollars) available for consumption. Consequently, the individual will attempt wherever possible to trade off consumption for more leisure. They can achieve this by working fewer hours, as well as by managing T2DM risk and progression by engaging in health-related activities that involve relatively little time—namely, LTPA and pharmacotherapy. Of note, while dedicating time to regular physical activity detract from achievement of the decision-maker's immediate well-being, it is still the least time-intensive means available to manage the risk of developing T2DM and its progression.

When consumption and leisure are (perfect) substitutes, the decision-maker is not motivated to balance the intake of each good. Given that decision-makers value one unit of consumption or leisure equally (as reflected in the baseline value of the distribution parameter), their best course of action is to stockpile whichever commodity can be most easily amassed. Because of how the model defines consumption and leisure, the former is a more suitable candidate in this regard. This is best demonstrated with reference to the decision to adopt healthy eating habits, which, while requiring that an additional 365 units (i.e., hours) of (what would otherwise be) leisure be allocated to meal preparation, has the potential to free up thousands of dollars of income per year (see Table 8 on page 129 above). The baseline price of consumption ($1/unit) is such that eating healthfully enables the decision-maker to significantly increase their within-period reward while also helping to reduce their risk of developing T2DM and manage its progression. A similar logic suggests that LTPA—adherence to which requires 130 hours per year—is generally preferable as means of managing T2DM when compared to pharmacotherapy—adherence to which has the potential to cost hundreds or even thousands of dollars per year.

Optimal policies vary little with changes in the price of consumption goods:

- When consumption and leisure are complements in the production of utility, differences appear exclusively in choices taken by decision-makers who are experiencing unemployment, and only in cases where they are healthy or have just been diagnosed with T2DM. When prices fall below the default level employed in the baseline analysis, the unemployed (like the employed) engage in regular physical activity while eschewing healthy eating habits, while they do the opposite when prices rise above this level. This occurs because while the action space in the decision model consists mostly of bundles that are "consumption-heavy", as noted above, this is not necessarily true for income-constrained EIA recipients—who may be compelled to divert income to consumption when its prices is high to ensure consumption and leisure can be enjoyed in the proper proportions.

- When consumption and leisure are readily substitutable, individual decision-making is largely uncorrelated with the price of consumption over the ranges considered in this analysis—although the impacts on individual well-being, as reflected in the value function, are pronounced. Reductions relative to the baseline have little effect on the individual's choices because they are already employing all mechanisms at their disposal for maximizing consumption. Increases above baseline value also minimally affect the individual's choices, but for a rather different reason: despite the increase, units of consumption can still be accumulated more easily than units of leisure—although this would not remain true if the price were to increase still further.

4.2.2 Preferences over consumption and leisure

The current version of the model uses the following expression (reproduced here from Equation (14) in Chapter 3) to represent the mechanism through which individuals combine consumption, leisure, and health-related quality of life (HRQoL) to contribute to their own well-being:

$$u_t\left(f\left(h_t\right),c_t,\ell \qquad \ell \qquad \ell \quad {}^{\gamma}$$

As shown, the expression is a variant of the standard CES utility function in which enjoyment from consumption and leisure is weighted by the HRQoL associated with their current health state—where HRQoL ranges from zero to one, with zero representing being deceased and one representing perfect health.

Preferences over consumption and leisure are captured in the value of the single parameter α, which lies in [0, 1]. Values of α approaching one denote strong preferences for consumption relative to leisure, while values approaching zero indicate the opposite. This observation, combined with the discussion in Section 3 above, motivates the following general predictions about how the features of the optimal policy should change as we vary the value of α:

- For very high values of α, people will prioritize consumption, which should manifest in continuing to work past the standard age of retirement and eschewing part-time work, while exhibiting a preference for health-related behaviours that require little or no financial outlay, such as physical activity.

- For very low values of α, people will prioritize leisure, which should manifest in disinclination to work past the standard age of retirement, a tendency to work on a part-time basis, and a preference for health-related behaviours that require little or no time commitment, such as adherence to pharmacotherapy.

Table 45 in Appendix G presents the results from this part of the sensitivity analysis:

- As predicted, labour market participation is tied to preferences over consumption and leisure. When people possess a very strong preference for leisure (i.e., $\alpha < 0.25$), they often work less intensively than otherwise and exit the labour market upon being able to access personal savings and public pensions. At higher values of α, people exhibit little appetite for part-time work and commonly extend their working lives well past the standard age of retirement; when $\alpha = 1$, for example, the decision-maker will continue to work well into their 80s.

- ❖ Adoption of health-related behaviours among healthy individuals tends to follow a consistent pattern. For low values of α, people will manage their risk of developing T2DM by engaging in regular physical activity, but not healthy eating habits. This is as expected, since the additional time required for meal preparation far exceeds the time needed to adhere to LTPA. As α rises, we observe the opposite. People now focus on eating healthfully rather than LTPA, since the income they save in so doing is more valuable to them than the leisure they must sacrifice. When $\alpha = 1$, people adhere to both behaviours.

- ❖ Among individuals who have been diagnosed with T2DM, we observe a negative association between α and adherence to pharmacotherapy. Of note is that unemployed individuals may opt not to adhere to pharmacotherapy when α is relatively large, despite being exempt from Pharmacare deductibles; this reflects recognition that the exemption will end upon finding work, and that they might then be compelled to stick to a commitment they no longer regard as favourable. Association between α and adherence to LTPA and healthy eating habits is more complicated:

- People with strong preferences for leisure often do not adopt healthy eating habits but will tend to adhere to LTPA and pharmacotherapy. This is observed irrespective of whether their condition was recently diagnosed, or whether they've lived with it for several years.

- For people with strong preferences for consumption, behaviour depends upon age, duration of T2DM, and employment status. If recently diagnosed, prior to the standard age of retirement people will adhere to both LTPA and healthy eating habits but not comply with physician-prescribed medications; at age 65 or older, they will usually engage only in healthy eating habits. We observe similar behavior in those diagnosed many years prior, excepting a more pronounced disinclination to engage in LTPA. Irrespective of T2DM duration, at intermediate values of α employed individuals will sometimes elect to engage in regular physical activity at the expense of healthy eating habits, while their unemployed counterparts do the opposite. The rationale for this is the same as described in Section 3.2 above.

4.2.3 Intertemporal preferences

As noted in Section 3.7 in Chapter 3, the discount factor reflects the extent to which individuals regard enjoying a unit of consumption today as preferable to doing so tomorrow, and falls in the closed interval [0, 1]. Values close to zero indicate individuals place little value on consumption or leisure available after the current decision epoch, manifesting in disinclination to defer opportunities to enjoy these. Conversely, values close to one indicate individuals weight current and future well-being about equally, manifesting in willingness to sacrifice consumption and leisure in the present when this is beneficial in the longer term.

The design of the decision model is such that motivation to adhere to LTPA, healthy eating habits and pharmacotherapy relies to a significant extent on an individual's capacity to delay gratification, since these activities do not generate utility in themselves and typically draw down resources that could be used to do so. One important exception to this is dietary expenditures, since the process of selecting parameter values in Chapter 3 (page 119) suggested healthful eating may in some circumstances be more economical than the alternative. This implies we would typically expect the optimal policy to be characterized by greater (less) adherence to health-related behaviours as the discount factor approaches 1 (0).

While the model assumes a discount factor of 0.95 by default, I consider several other possible values for this parameter, including 1.00, 0.75, 0.50 and 0. The results of this component of the sensitivity analysis are presented in Table 46 in Appendix G. As shown, the results generally conform with expectations:

- Among healthy people, for very low values of δ, non-adherence to health-related behaviours is common for employed individuals. Those who are unemployed, meanwhile, typically adhere to healthy eating habits while neglecting LTPA, as this enables them to conserve income. As δ rises, we typically see a familiar pattern whereby individuals who are employed adopt healthy eating habits but not regular physical activity, while their unemployed counterparts do the opposite. There are two exceptions to this:
  - The youngest individuals incorporated into the model (i.e., 25-year-olds) never adhere to LTPA, which again reflects the existence of a "grace period" during which actions do not have health-related consequences.
  - After withdrawing from the labour force, people will usually eat healthfully (except at very low values of δ), but never participate in regular physical activity.

- Similar patterns appear in those newly diagnosed with T2DM, although pharmacotherapy now comes into play:
    - At low and intermediate values of δ (i.e., 0.75 and below), most employed individuals are completely non-adherent with health-related behaviours, but as willingness to delay gratification grows, they exhibit a tendency to engage in LTPA and self-administer prescribed medications.
    - Unemployed decision-makers adhere to healthy eating habits when δ is low because they value the incremental income more than the extra time needed to prepare healthy meals. They also adhere to prescribed medications, since they are exempt from paying Pharmacare deductibles, and, at higher levels of δ, because they also recognize it is in their best interest to sustain this behaviour even if they subsequently recover employment (and so no longer enjoy the exemption).[35]
- Once people reach the standard age of retirement, their behaviour shifts. When the decision-maker heavily discounts future consumption and leisure,

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[35] With regards to medication adherence, it is worthwhile comparing this pattern of behavior with the baseline analysis, where some newly-diagnosed unemployed people elect not to adhere to pharmacotherapy, recognizing this entails a financial commitment they are unwilling to sustain when they recover employment.

they now abstain from health investment irrespective of employment status. This occurs because unemployed individuals are now eligible to access public pensions and personal savings (and so need not conserve income) and no longer qualify for exemption from the Pharmacare deductible. As δ rises, decision-makers begin adopting healthy eating habits and pharmacotherapy, recognizing (or at least valuing) its potential to promote future well-being by slowing diabetic progression.

- At advanced ages, decision-makers will begin eating better (and less costly) diets primarily because they have exhausted their personal savings. However, they will tend not to otherwise invest in health unless they are particularly patient (i.e., unless δ is very high).

- Broadly speaking, adherence patterns for individuals who have lived with T2DM for prolonged periods resemble those seen in individuals who were diagnosed more recently. Where differences exist, they tend to emerge at intermediate and very high values of the discount factor and revolve around a predilection (i.e., relative to newly-diagnosed individuals) for healthy eating habits and a disclination to engage in LTPA or adhere to pharmacotherapy. These choices can again be interpreted with reference to the comparatively high costs of pharmacotherapy confronting those who have lived with T2DM for many years, as well as the likelihood that they will have experienced microvascular and macrovascular complications that, if underweight, place them at increased risk of all-cause mortality.

4.2.4 Age-related productivity decline (ARPD)

Section 3.6.4 in Chapter 3 noted that one economic explanation for the decision to retire is declining productivity that may accompany the transition to old age and that may make work cessation more attractive, particularly if other sources of income exist. However, examining the association between age and productivity is methodologically challenging (Blundell et al., 2016, pp. 488, 490; Dostie, 2011; Luong & Hébert, 2009; Thornton, Rogers, & Brookshire, 1997), and valid estimates of this relationship are elusive at the present time.

As such, while the model assumes employment income declines at an annual rate of 2.5% after age 65, we consider here how adopting a range of plausible values (i.e., 0.0%, 1.0%, 2.5%, 5.0%, and 10.0%) influences the features of the optimal policy, particularly the timing of retirement. The results of this analysis—which are presented in Table 47 in Appendix G—lead to the following observations:

- When productivity does not decline with age or declines only very slowly (i.e., 1% annually), people who have succeeded in retaining employment up to a given decision epoch often choose to continue working full time well past retirement, irrespective of their health state. Indeed, in the former case, decision-makers exhibit a willingness to sustain their attachment to the labour market right up until the end of their lives.

- At higher rates of ARPD (i.e., 2.5% or above), people will persist in delaying retirement by a few years (unless they have an established history of T2DM and have previously managed their condition poorly), but no longer exhibit willingness to remain in the labour force at advanced ages if not retired by that time. This occurs because their productivity will have deteriorated to such a degree that the consumption they can finance by continuing to work is insufficient to compensate for the added leisure they can enjoy by retiring.

- Overall, health behaviours closely resemble the baseline scenario. Where variation exists, it is typically tied to differences in the individual's labour market decisions. For example, the tendency to sustain participation in regular physical activity to advanced ages when APRD is negligible—which we do not observe in the baseline scenario—is linked to continued attachment to the labour market, and speaks to a desire to preserve health without sacrificing too much of an input which, for those who work, is relatively scarce (i.e., time).

The above observations suggest the model behaves as expected in response to variability in the value of this parameter. They also suggest that an annual rate of age-related productivity decline of 2.5% is reasonable for the purposes of this research, since people do not typically work until the end of their lives (as the model predicts should happen if productivity does not decline with age), and since it is not credible to assume productivity declines rapidly beyond age 65.

4.2.5 Dietary costs

As discussed in Section 2.5.1 in Chapter 2, there is presently no consensus in the literature regarding the relationship between dietary quality and cost. I sought to address this gap by designing and carrying out my own dietary costing exercise, the methodology for, and results of which are presented in Appendix B and Chapter 3 (Section 3.5.1), respectively.

The main finding emerging from the analysis is that lower quality eating habits characterized by high levels of caloric consumption are likely to entail financial costs as large or larger than better eating habits. However, due to the limitations and shortcomings of the methodology employed, it is important to assess the sensitivity of model-generated results to variation in dietary cost parameters. For the purposes of this analysis, I consider how the optimal policy changes when the expenditures associated with an unhealthy diet are twice, one-and-one-half, or half their current values, as well as when such eating habits can be sustained at no financial cost to the individual.

A summary of the results of this analysis—data tables for which are supplied in Appendix G (Table 48)—are as follows:

❖ Healthy individuals almost invariably favour the unhealthy diet when it is relatively inexpensive (i.e., half the baseline value or less), relying on regular physical activity to offset the impact of poor eating habits on their risk of T2DM. As expected, at higher values people will often switch from regular LTPA to healthy eating habits. For intermediate values of the dietary cost parameter (i.e., those close or equal to the baseline), adherence to health-related behaviours may depend on employment status among individuals who have not reached the standard age of retirement, in that those who are employed will choose to engage in LTPA but not eat healthfully, while those who are unemployed will do the opposite—as already discussed, this merely reflects the relatively higher value of additional consumption (leisure) to individuals confronting more severe constraints on income (time).

❖ Very similar patterns of behaviour are observed among individuals recently diagnosed with T2DM. Such individuals will also adhere to pharmacotherapy, except at advanced ages (i.e., age 80+).

- ❖ Among individuals who have already lived with T2DM for many years, choices regarding LTPA and dietary intake are nearly identical to those already described above. Decisions surrounding adherence to physician-prescribed medications, however, are driven to a significant extent by an individual's prior management of their condition: those who previously managed their condition well invariably choose to continue adhering with pharmacotherapy, but adherence is highly variable among those who were less vigilant in this regard earlier in life (the rationale for these patterns of behaviour, as they relate to patients complying with drugs prescribed to them by their physicians, is discussed in Section 3.2 above).

4.2.6 Additional robustness tests

Before proceeding, I conduct a series of robustness tests that investigate how the model responds to the imposition of unrealistic assumptions or the introduction of unlikely parameter values. The objective is again to verify that the results produced through this process align with expectations, given the model's design, the assumptions upon which it rests (e.g., values of parameters other than those I am varying), and the techniques applied to facilitate its solution.

Negligible risk of T2DM

The first test studies decision-making and individual well-being when the probability of developing T2DM is set to zero. In this context, we would expect healthy individuals to engage in LTPA and adopt healthy eating habits only if it is beneficial for reasons other than managing the risk of T2DM. We should observe little or no difference between the results of the test and those of the baseline analysis for individuals who already have T2DM.

The test results, which are presented in Table 49 in Appendix G, conform precisely with these predictions: features of the optimal policy and value function are identical to the baseline for individuals living with T2DM, and those who are healthy abstain completely from LTPA, adopting healthy eating habits only when they value the additional income this enables them to conserve more than the leisure they must sacrifice to facilitate enhanced meal planning and preparation.

Extreme Sleep Requirements

This test determines how the model responds to a change that forces the decision-maker to violate one of their constraints. I assume people must allocate 24 hours per day to sleep, leaving no time for other activities. This will have significant impacts because certain activities, such as meal preparation or job search, require a minimal outlay of time, and such outlays constitute a feature of most if not all model states. This choice of parameters should therefore force the decision-maker into a position where they absorb a large penalty during every decision epoch irrespective of their actions.

The test results are presented in Table 50 in Appendix G. As shown, modifying individual sleep requirements does not inhibit the execution of the backward induction algorithm but produces large negative value functions, as anticipated. Review of the optimal policy suggests the individual's best course of action is to deliberately hasten mortality by abstaining from health-promoting activities (or by engaging in combinations of activities associated with an increased risk of all-cause mortality), since being deceased is the only state for which no penalty is incurred.

No Private Savings

The third test investigates the implications of nullifying the enforced savings mechanism outlined in Section 3.5.1 in Chapter 3—meaning, in effect, that individuals are required to subsist on public pensions alone. This implies a sizable decline in annual income, which should manifest in a desire to sustain attachment to the labour force for a greater duration than we observe in the baseline scenario. Because the model assumes people cannot earn income from both the labour market and public pensions concurrently, this approach is optimal only for so long as an individual's employment income generation capacity is sufficiently high that the former exceeds the latter.

The test results are presented in Table 51 in Appendix G. As expected, people do remain in the labour force longer when they cannot fall back on private savings during retirement. Of note is that value functions are larger than the baseline early in an individual's career (because they can immediately spend the income previously set aside for retirement), but lower later on (because this income and any interest it would have accumulated are no longer waiting for them once they reach the standard age of retirement).

Generous Basic Income

The fourth and final test examines decision-making and individual well-being in the context of a remarkably generous basic income program that gives all Manitobans one million dollars in pre-tax income each year, irrespective of whether they actively participate in the labour force. Since decision-makers enjoy the same level of income irrespective of whether (or how much) they work, they should have little incentive to supply labour and should withdraw from the labour force sooner than they otherwise would. In addition, health-related decision-making should be driven primarily by the goal of minimizing the risk of developing T2DM and the rate of diabetic progression while maximizing opportunities for leisure.

The test results presented in Table 52 in Appendix G bear out these predictions. While decision-makers are compelled to sustain attachment to the labour force prior to age 65, they work only part-time hours if employed (full-time status for unemployed workers is assigned arbitrarily and should not be interpreted literally), and they retire as soon as the model permits. In addition, they nearly always adhere with LTPA and prescribed medications but never with healthy eating habits. This is as expected: the decision-maker's efforts to reduce their risk of T2DM and manage its progression focus are largely insensitive to required financial outlays (note that the costs of pharmacotherapy invariably the individual's Pharmacare deductible) and revolve around preserving as much time as possible to engage in leisure.

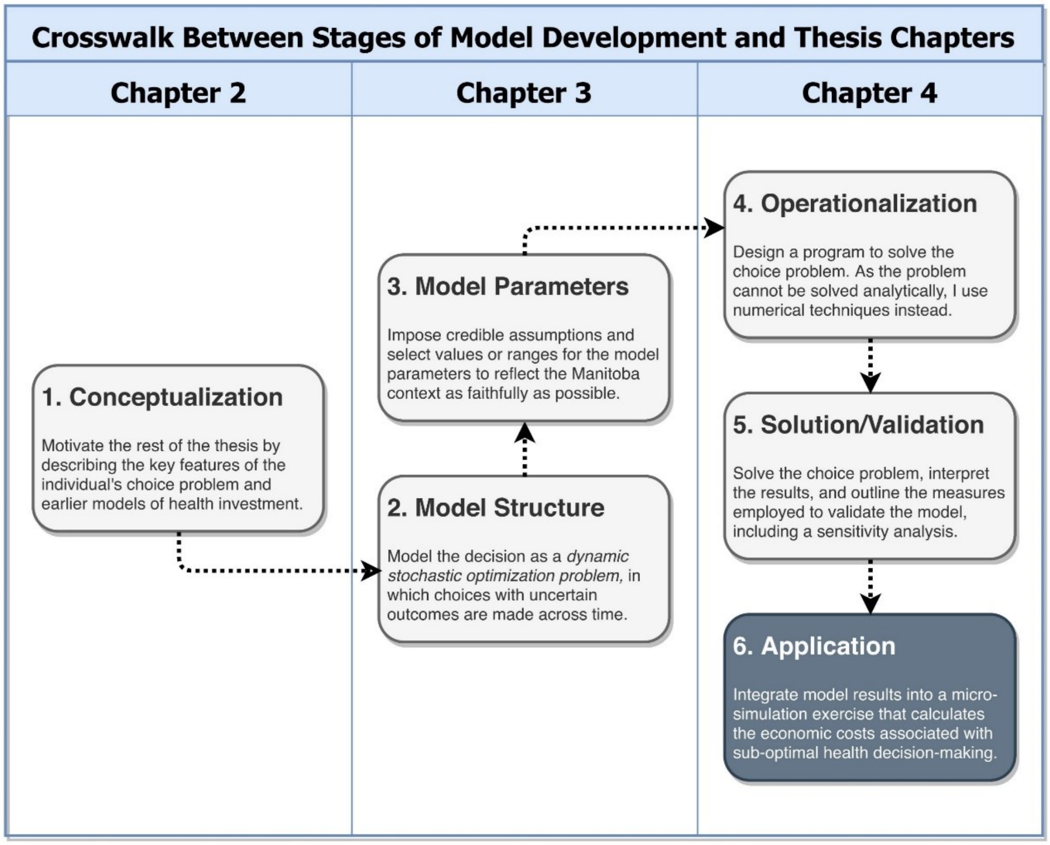
4.2.7 Summary

Review of the results of the sensitivity analyses suggests the optimal policy shifts in accordance with expectations in response to changes in preferences over, or the elasticity of substitution between consumption and leisure; the rate of time preference; the magnitude of age-related productivity decline; and, the financial cost associated with unhealthy eating habits. Moreover, results from a series of robustness tests that examine how the model responds to the imposition of unrealistic assumptions or the introduction of unlikely parameter values again align with our expectations. These results should offer a degree of assurance that the model has been correctly implemented.

5. APPLYING THE DECISION MODEL: CALCULATING INDIRECT LOSSES ATTRIBUTABLE TO T2DM AND ITS COMPLICATIONS

5.1 Rationale

One important contribution of this research is to supply a framework for investigating how rational, forward-looking decision-makers aware of the risks posed by T2DM or other chronic diseases might respond to an existing or hypothetical health intervention. However, the thesis was also designed to serve a secondary function, drawing upon the insight that health and economic outcomes resulting from optimal health-related decision-making can serve as a baseline for evaluating other possible strategies available to the individual for preventing and/or managing T2DM. Contrasting outcomes resulting from what people have done or might do with what they *should* do enables researchers and policy-makers to quantify potential gains from implementing regulations, policies, programs and interventions that nudge individuals closer to optimizing behaviour.



To this end, I have developed a patient-level microsimulation model that draws upon outputs generated by the decision model to simulate long-term health and economic outcomes within a cohort of young Manitobans, under varying assumptions about adherence to health-related behaviours over time, including, but not limited to patterns of behaviour consistent with the solution to the dynamic optimization problem. This section demonstrates one policy application of the decision model, contrasting productivity losses attributable to T2DM and its complications when people commit to the optimal policy with those resulting from other possible strategies for preventing and managing T2DM.

While implied by the discussion above, I emphasize that microsimulation exercises undertaken using outputs derived from the decision model are not suitable for predicting outcomes in actual patient cohorts, since people do not always or even generally resemble the fully-rational, forward-looking economic agents posited by the model. Although it is certainly possible to formulate such predictions from observations or reasonable assumptions about health-related choices, as others have done in the past, part of this thesis' contribution is to go one step further, furnishing researchers and policy-makers with a framework for studying differences in health or economic outcomes resulting from decisions that stray from optimality.

5.1.1 T2DM in Manitoba

Administrative data collected by Manitoba Health, Seniors and Active Living (2018a) indicates that 118,734 Manitobans age one or older—approximately 9.1% of the provincial population—had diabetes in Fiscal Year 2015/16 (page 25). The results further suggest that the prevalence of T2DM

- has steadily increased in Manitoba over the last decade;

- is consistently higher in men than in women, and may be increasing more rapidly in the former; and,

- is highly variable across the province, ranging from 7.0% in Southern Health-Santé Sud to 18.2% in the Northern Health Region, with prevalence in the City of Winnipeg resting at approximately 8.6% (Manitoba Health, Seniors and Active Living, 2018a, fig. 19).

The prevalence and incidence of diabetes in Canada rises with age, increasing sharply after 40, and reaching a maximum in the 80-84 age group, within which it affected nearly one-third (33.2%) of males and more than one-quarter (25.9%) of females in 2013-2014 (Public Health Agency of Canada, 2017). However, the greatest *increases* in prevalence between FY 1998/99 and FY 2008/09 were found in Canadians aged 35-44, which the Public Health Agency of Canada (2011b) attributes to rising rates of overweight and obesity (p. 17). The prevalence of T2DM has increased particularly rapidly in Indigenous Peoples. For example, some evidence suggests that the prevalence of T2DM is 3-5 times higher among First Nations people than the Canadian population more generally (Health Canada, 2014).

From an economic standpoint, it is noteworthy that more than half of Canadians diagnosed with diabetes are of working age (Public Health Agency of Canada, 2011a, pp. 4, 15). This fact, combined with a growing literature that documents the detrimental impact of T2DM on labour force participation and performance (summarized in Section 2.2.3 in Chapter 2) suggests T2DM is imposing and will continue to impose large costs on the Canadian and Manitoban economies—a point to which I now turn.

5.1.2 Previous studies of the direct and indirect costs of T2DM

Direct and indirect costs of illness refer, respectively, to health care expenditures (e.g., in-patient and out-patient care and medication use) and to costs associated with diminished labour market productivity resulting from disease-related morbidity and mortality (Boccuzzi, 2003, p. 63).

Many Canadian studies have derived estimates of the direct costs associated with T2DM and/or its complications (Bilandzic & Rosella, 2017; Canadian Diabetes Association, 2009; Goeree et al., 2009; Health Canada, 2002; Ohinmaa, Jacobs, Simpson, & Johnson, 2004; Public Health Agency of Canada, 2014, 2018a; Rosella et al., 2016), including a few focused specifically on Manitoba (Canadian Diabetes Association, 2011a; Finlayson et al., 2010; P. Jacobs, Blanchard, James, & Depew, 2000).

Relatively few Manitoban or Canadian studies, by contrast, have attempted to estimate the indirect costs associated with T2DM and/or its complications. Likely the best-known of these is the *Economic Burden of Illness in Canada (EBIC)* report series published by Health and Welfare Canada (1991), then by Health Canada (1997, 2002), and currently by the Public Health Agency of Canada (2014, 2018a).

EBIC 1998, for instance, calculated that total indirect costs attributable to diabetes lay between $1,261.9-$1,313.6 million during that year (Health Canada, 2002).[36] More recently, EBIC 2005-2008 estimated that indirect costs attributable to diabetes amounted to approximately $145.2 million in 2008 (Public Health Agency of Canada, 2014, p. 12). Of note is the fact that EBIC 1998 employed a human capital approach to indirect cost estimation, whereas EBIC 2005-2008 instead applied a friction cost approach, which commonly produces much lower estimates (see Footnote 37 below).

I succeeded in identifying only a single estimate of the indirect cost of diabetes in Manitoba, which was published by the Canadian Diabetes Association (2011a)

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36 This includes $732.8 million and $529.1 million in productivity losses associated with premature mortality and long-term disability, respectively; the report notes that endocrine and related diseases were responsible for an additional $51.7 million in short-term disability costs, but does not indicate what proportion of this is attributable to diabetes (Health Canada, 2002, pp. 39, 46, 52).

using its Canadian Diabetes Cost Model. That study predicted that the economic burden of diabetes in Manitoba would reach approximately $640 million, of which over four-fifths ($514 million) was expected to derive from a combination of premature mortality and short- and long-term disability costs (Canadian Diabetes Association, 2009, p. 8, 2011a, p. 4).

Although the methodologies applied in these studies vary, taken together their results suggest productivity losses account for a sizable share of the economic burden of T2DM in Manitoba. As such, this represents an area where this thesis can potentially make an important contribution.

5.2 Methodology

This section calculates prevalence, incidence and indirect costs of T2DM in a cohort of Manitobans who were 25 years old in 2017, under varying assumptions about how and to what extent cohort members invest in their health. It achieves this using patient-level microsimulation techniques that track the health and economic outcomes of individual decision-makers over time.

5.2.1 Key features of the approach

The simulation model has the following characteristics:

- *Application of Monte Carlo simulation techniques.* The simulation model employs Monte Carlo simulation techniques, which in this context involve repeatedly sampling from predefined (i.e., uniform) probability distributions, comparing the result to the transition probabilities implied by a person's state and the action they've taken, and assigning a new state based upon the result (Brandimarte, 2014, Chapter 1; Clemen, 1996, Chapter 11).

- *Integration with the decision model.* An important goal for this thesis is to demonstrate the integration of dynamic optimization techniques and microsimulation modelling, thereby enabling researchers to evaluate the potential economic gains associated with optimal health-related decision-making relative to other patterns of behaviour (which could—but presently does not—include another optimal policy formulated by decision makers in response to an actual, planned or hypothetical intervention). The simulation model in this thesis compares optimal policies derived when decision model holds parameters at baseline values, against two alternate policies characterized by complete adherence or non-adherence to LTPA, healthy eating habits, and pharmacotherapy.

- *Focus on indirect costs.* As currently configured, and for the reasons discussed in Section 5.1, the simulation model currently focuses on calculating the indirect costs associated with T2DM and its complications, including costs associated with absenteeism, presenteeism and premature mortality. The simulation model does not currently tabulate direct costs but could be modified to do so.

5.2.2 Metrics included in the simulation model

The simulation model tracks the following outcomes over time for each member of the simulation cohort:

- *Prevalence.* Prevalence is the proportion of the simulation cohort diagnosed with T2DM during that or any earlier epoch, that is alive when performing the calculation.

- *Incidence.* This is the number of new cases of T2DM diagnosed within the simulation cohort during each decision epoch, from among those who were healthy during the preceding epoch. As is common in the literature, I express incidence in terms of new cases of T2DM per thousand person-years.

- *Efficiency losses attributable to absenteeism.* This refers to losses attributable to illness that result from workplace absence. The simulation model expresses this in terms of the dollar value of additional labour market earnings an individual would have accrued had they been present (i.e., the product of hourly earnings and the number of hours absent from work).

- *Efficiency losses attributable to presenteeism.* This refers to losses attributable to illness that result from functioning at reduced capacity in the workplace. The simulation model expresses this in terms of the product of the dollar value of wages an individual would have earned had they worked at full capacity (i.e., the product of hourly earnings, the number of hours worked while ill, and the productivity decrement applied to each hour of illness).

- *Efficiency losses attributable to premature mortality.* This refers to losses resulting from people with T2DM dying before voluntarily transitioning out of the labour force. I express this in terms of the dollar value of wages a deceased individual would have earned between the year they died and the year they were expected to retire. For the purposes of this analysis, premature mortality applies to all deaths among individuals with T2DM (whereas individuals with T2DM can experience mortality for reasons unrelated to their condition).

It is important to add two observations about the metrics incorporated into the microsimulation model. First, the model employs a human capital approach to determine productivity costs,[37] which is to say that it expresses indirect costs in terms of gross earnings of those employed in the labour market (Drummond et al., 2015, p. 247; Krol & Brouwer, 2014, p. 339). Unlike other studies, however, it does not assign a value to unpaid labour. Second, the simulation model does not currently examine the distribution of efficiency losses between workers, employers, and others, although it could in the future be modified to do so.

5.2.3 The starting cohort

The simulation model can in principle accommodate any starting cohort, provided one specifies the gender, ethnicity, education, and initial state of each member of the cohort. By necessity, we employ the same ethnic categories incorporated into the UKPDS-OM2, namely Caucasian, Afro-Caribbean or Asian-Indian (we discuss this further below). Levels of educational attainment derive from the classification scheme incorporated into the 2011 NHS, and include no certificate, diploma or degree; high school diploma or equivalent; post-secondary certificate

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[37] Another common approach to estimating indirect costs is the friction cost method, which conceptualizes losses in terms of the time firms require to restore the original level of production; estimates derived using the friction cost approach are typically much lower than those derived using the human capital approach (Drummond et al., 2015, pp. 247–248; Krol & Brouwer, 2014, p. 339).

or diploma below bachelor level; and, university certificate, diploma, or degree at bachelor level or above.

As noted, the model also requires the user to specify the state each member of the cohort occupies at the outset of the simulated time horizon, including their age, their initial state of health (i.e., healthy, diabetic, or deceased), time elapsed since diagnosis with T2DM, where applicable, and employment status.

For the purposes of the simulation exercise, the starting cohort consists of Manitobans who were 25 years of age on June 1st, 2017, the size of which is obtained from administrative data maintained by Manitoba Health, Seniors and Active Living (2018b). For simplicity, we assume that all members of the cohort are initially both healthy and employed in the provincial labour market. The composition of the cohort mirrors the composition of the Canadian population in the age 25-29 age group with respect to gender, ethnic background and education, as reflected in the PUMF for the 2011 NHS (there were too few Manitoba observations from the PUMF in this age group to ensure representativeness).

Table 29 summarizes the characteristics of the starting cohort:

Table 29: Characteristics of the starting cohort				
Ethnicity	**Education**	**Male**	**Female**	**Total**
Afro-Caribbean	No certificate, diploma or degree	28	33	61
Afro-Caribbean	High school diploma or equivalent	85	64	149
Afro-Caribbean	Post-secondary certificate or diploma below bachelor level	101	129	230
Afro-Caribbean	University certificate, diploma, or degree at bachelor level or above	59	85	144
Asian-Indian	No certificate, diploma or degree	281	232	513
Asian-Indian	High school diploma or equivalent	521	430	951
Asian-Indian	Post-secondary certificate or diploma below bachelor level	644	662	1,306
Asian-Indian	University certificate, diploma, or degree at bachelor level or above	828	1,043	1,871
Caucasian	No certificate, diploma or degree	874	511	1,385
Caucasian	High school diploma or equivalent	1,952	1,357	3,309
Caucasian	Post-secondary certificate or diploma below bachelor level	2,996	2,715	5,711
Caucasian	University certificate, diploma, or degree at bachelor level or above	1,839	2,666	4,505
Total	**Total**	**10,208**	**9,927**	**20,135**

Source: Manitoba Health, Seniors and Active Living (2018b, p. 12); Statistics Canada (2014)

It is essential to highlight the approach used to align the classification of ethnicity used by Statistics Canada through the 2011 NHS with the ethnicities incorporated into the UKPDS-OM2. A person is categorized as

- Caucasian if they are recorded in the PUMF as being "white" or "white and visible minority(ies)" or if ethnicity is not reported;

- Afro-Caribbean if they are recorded in the PUMF as being "black"; and,

- ❖ Asian-Indian, if described otherwise. This includes individuals who are categorized as "Arab" OR "visible minority" OR "multiple visible minorities".

5.2.4 The sampling mechanism

The simulation model serving as the basis the results outlined in this section was adapted from the *mdpsim* function included in Paul Fackler's MDPSolve package, which, given a set of initial starting states and a matrix of optimal transition probabilities, illustrates the types of outcomes decision-makers may experience and how they will respond. The original function is ideal for optimization problems with relatively small numbers of states but proved unworkable for my purposes because of the decision model's substantial state space.[38]

The modified program pulls random draws from the uniform distribution and compares them to cumulative transition probabilities derived from the optimal transition matrix. As depicted in Figure 5 below, the decision-maker's state in the next decision epoch is the one corresponding to the range of values within which the random draw fell. Conceptually, once the new state is revealed, each

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38 For each initial state, the original function tabulated transition probabilities for every possible end state; this would have implied generating arrays consisting of 52.1 billion cells, requiring much more working memory than I had available. The modified function calculates cumulative transition probabilities for only a minute subset of allowable state transitions and so requires much less memory.

simulated agent consults their optimal policy (or a policy specified by the user) to determine what course of action to pursue; this choice then determines the set of probabilities governing next period's state transition.

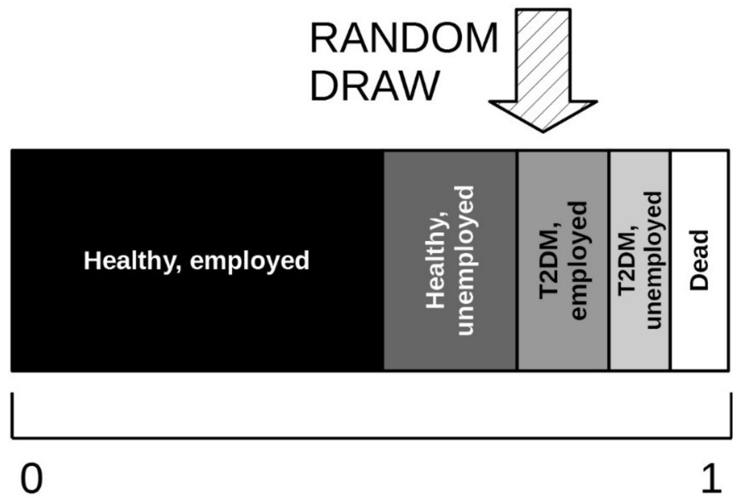

Figure 5: Visual representation of the simulation of health and employment state transitions through random number generation

The results presented in this section derive from a single set of uncorrelated random draws from the uniform distribution. That is, the same set of random numbers governs transitions for every scenario incorporated into the analysis. This implies that for any given initial state, if two scenarios have the same vector of cumulative transition probabilities, the individual will experience the same event in both. While not undertaken here, one could in principle add an outer loop to the microsimulation model, for example to perform a probabilistic sensitivity analysis in which one or more parameters varies over predefined ranges.

5.3 Simulation results

The simulation analysis considers three distinct scenarios.

- The first scenario compares health and economic outcomes when members of the cohort adopt the optimal policy generated by the decision model, versus an alternate policy involving unconditional adherence to LTPA, healthy eating habits, and pharmacotherapy, where applicable. It is important to emphasize that health and economic outcomes for individuals adopting optimal or unconditional adherence will tend to vary to some extent. This occurs because fully-rational, forward-looking decision-makers sometimes perceive it is not in their best-interest to engage in some health behaviours capable of reducing the risk of developing T2DM or slowing its progression (see Section 3).

- The second scenario contrasts outcomes emerging from adoption of the optimal policy versus a strategy characterized by uniform non-adherence to any of the health behaviours incorporated into the model.

- The third scenario compares outcomes with adoption of the optimal policy against those associated with commitment to a more complicated pattern of behaviour, in which individuals who are initially non-adherent to healthy lifestyle habits modify these in response to a T2DM diagnosis so as to bring them in line with their optimizing peers.

5.3.1 Scenario 1: Optimal policy versus complete adherence

As already noted, the first scenario examines what happens when two otherwise identical cohorts pursue different strategies to mitigate or manage the risks associated with T2DM. The first mirrors the solution of the dynamic optimization problem. The second strategy prescribes blanket adherence to regular physical activity, a healthy diet, and medication.

A detailed data table presenting results from the first simulation is included in Table 53 in Appendix H, which we describe in greater depth below.

Incidence and prevalence of T2DM

As shown in Figure 6, the simulated incidence and prevalence of T2DM across the two cohorts is similar, although prevalence is in fact marginally higher under the optimal policy even while the incidence is identical at every point in time across the groups. This apparent contradiction can be explained with reference to the parameters of the UKPDS-OM2 risk equations, which, as noted in Section 3.2 suggest a higher risk of all-cause mortality among underweight (i.e., BMI < 18.5 kg/m^2) diabetics with a history of micro- or macrovascular complications who have not experienced any events in a given year. Due to the approach this study uses to model the attainment of equilibrium weight and BMI (outlined in Section 3.6.1 in Chapter 3), people who engage in both regular physical activity and healthy eating habits—a pattern of behaviour characteristic of the alternate policy *but* not the optimal policy—are commonly underweight, and may be more likely to experience mortality as a result. Once deceased, these individuals are no longer categorized as ill, and, therefore, are not incorporated into the prevalence calculation.

Review of Figure 6 also reveals spikes in disease incidence during the fifth and seventh decades of life that manifest in noticeable increases in the rate of growth of T2DM prevalence at those times. This phenomenon is consistent with the observation that the risk of developing T2DM increases with age (see Section 2.4.1 in Chapter 2), and reflects the structure of the DPoRT 2.0 risk equations, which specify different parameters for those younger than 45, those between the ages of 45 and 65, and those aged 65 or older.[39]

[39] The equations contain two age groups for men (i.e., age < 45 and age ≥ 45), and three for women (i.e., age < 45, $45 \leq$ age < 65 and age ≥ 65) (Rosella, Lebenbaum, Li, Wang, & Manuel, 2014, p. 21).

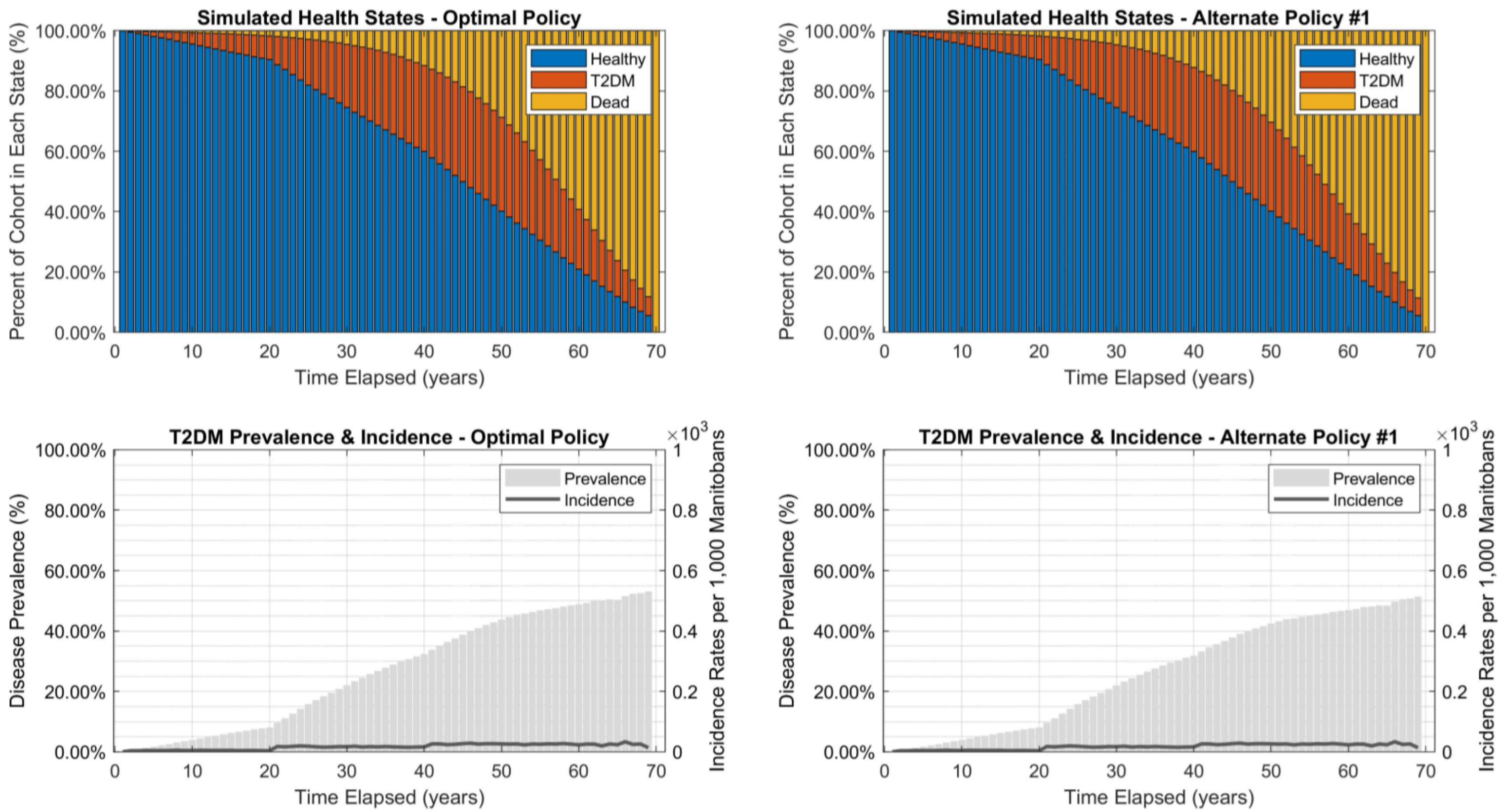

Figure 6: Projected prevalence and incidence of T2DM in Manitoba (Alternate Policy #1)

Indirect costs

Figure 7 reports indirect costs attributable to T2DM among two otherwise identical cohorts that pursue either the optimal policy or an alternate policy involving complete adherence to all measures available for promoting and preserving health.

Total annual costs grow exponentially over time, becoming pronounced beginning in the fifth decade of life (i.e., 15+ years elapsed), peaking in the years prior to the standard age of retirement and declining sharply thereafter. Accumulation of indirect costs reflects the increasing incidence and prevalence of T2DM in the simulated cohort over time (i.e., a growing proportion of the labour force begins to experience productivity losses), as well as the progressive character of T2DM (i.e., productivity losses are correlated with duration of T2DM, because this allows more time for microvascular and macrovascular complications to develop). Inspection of Figure 7 reveals exponential growth in simulated efficiency losses to be driven largely by premature mortality within the cohort, since losses attributable to workplace presenteeism and absenteeism accumulate much more gradually.

The sharp decline in all indirect cost components beginning at age 65 is consistent with the simulation model's focus on productivity losses experienced in the workplace, which does not assign a valuation to either leisure or unpaid work, and therefore disregards losses incurred by those who have retired.

In both scenarios, presenteeism initially constitutes the largest proportion of indirect costs; however, as simulated time passes, absenteeism begins to claim an increasing share of productivity losses. As members of the cohort enter their early 50s, losses resulting from premature mortality begin to eclipse both absenteeism and presenteeism, and they continue to dominate costs thereafter. Over the entire life of the cohort, absenteeism, presenteeism and premature mortality account, respectively, for 24.2%, ($174.9 M), 23.3% ($167.9 M) and 52.5% ($379.1 M) of total indirect costs under the optimal policy, and for 20.2% ($136.2 M), 24.3% ($163.9 M) and 55.6% ($375.2 M) of costs under the alternate policy.

Thus, premature mortality accounts for the largest share of indirect costs in both simulations. The remaining costs are divided (more or less) evenly between efficiency losses attributable to workplace absenteeism and presenteeism. Under the optimal policy, however, absenteeism accounts for a relatively larger share of indirect costs (i.e., relative to the alternate policy), while presenteeism and premature mortality account for smaller shares. In absolute terms, by contrast, all cost components are larger under the optimal policy.

Total lifetime indirect costs associated with optimal and alternate policies are $721.9 M and $675.3 M, respectively (or $278.4 M and $260.8 M in present value [PV] terms). Adopting the optimal policy is therefore associated with additional indirect costs of $46.6 M (PV: $17.5 M) when compared with a strategy involving full adherence to all health behaviours incorporated into the decision model.

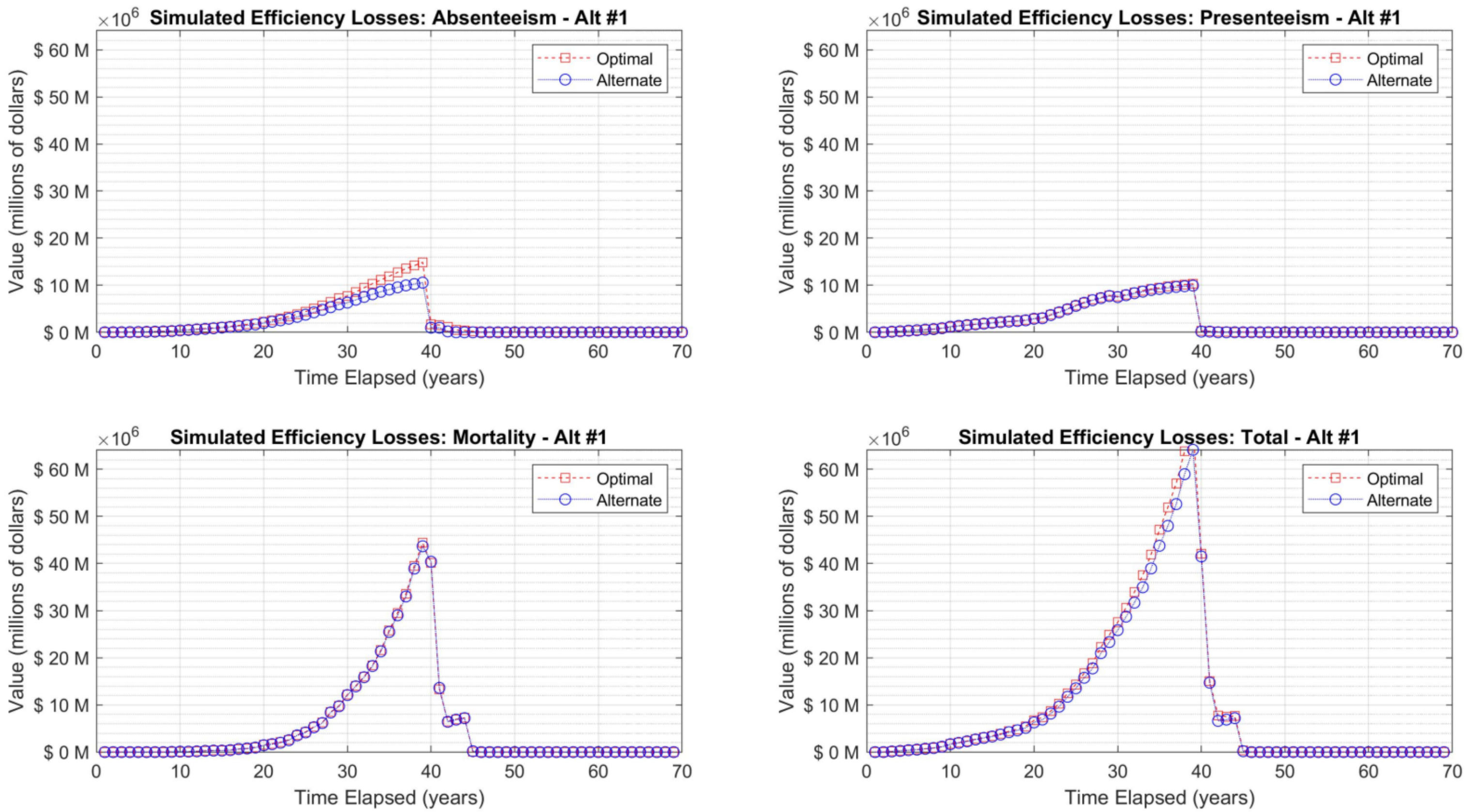

Figure 7: Projected efficiency losses attributable to T2DM in Manitoba (Alternate Policy #1)

5.3.2 Scenario 2: Optimal policy versus complete non-adherence

The second scenario also examines what happens when two otherwise identical cohorts pursue different strategies to mitigate or manage the risks associated with T2DM. As before, the first mirrors the solution of the dynamic optimization problem. This time, however, the second strategy entails total non-adherence to regular physical activity, healthy eating habits and physician-prescribed medications.

A detailed data table presenting results from the second simulation is included in Table 54 in Appendix H.

Incidence and prevalence of T2DM

As shown in Figure 8, in this scenario T2DM incidence and prevalence evolve in very different ways across the two cohorts.

When people pursue the optimal policy, growth in prevalence is comparatively gradual during the first two decades of the simulation but accelerates thereafter, tapering off towards the end of the simulation before picking up once more in the final years of life. Correspondingly, we initially see low incidence rates that increase in the fifth and seventh decades of life.

Prevalence under the alternate scenario, by contrast, spikes almost at once and continues increasing at a declining rate. There is a momentary interruption of this trend two decades into the simulation (again reflecting the structure and parameters of the DPoRT 2.0 risk equations, which manifest in a permanent increase in the likelihood of developing T2DM at age 45), but prevalence increases at a diminished rate thereafter and effectively plateaus within a decade of reaching the standard age of retirement. Correspondingly, we initially see high but slowly declining incidence rates that increase after two decades, achieving a new, higher plateau around which incidence rates fluctuate while slowly declining over the rest of simulated time.

The implication of these results, as examination of Figure 8 demonstrates, is a dramatic increase in the prevalence of T2DM among those who elect not to adhere to LTPA, healthy eating habits or pharmacotherapy, resulting in more than nine-tenths of the surviving cohort living with diabetes by the time its members reach the standard age of retirement.

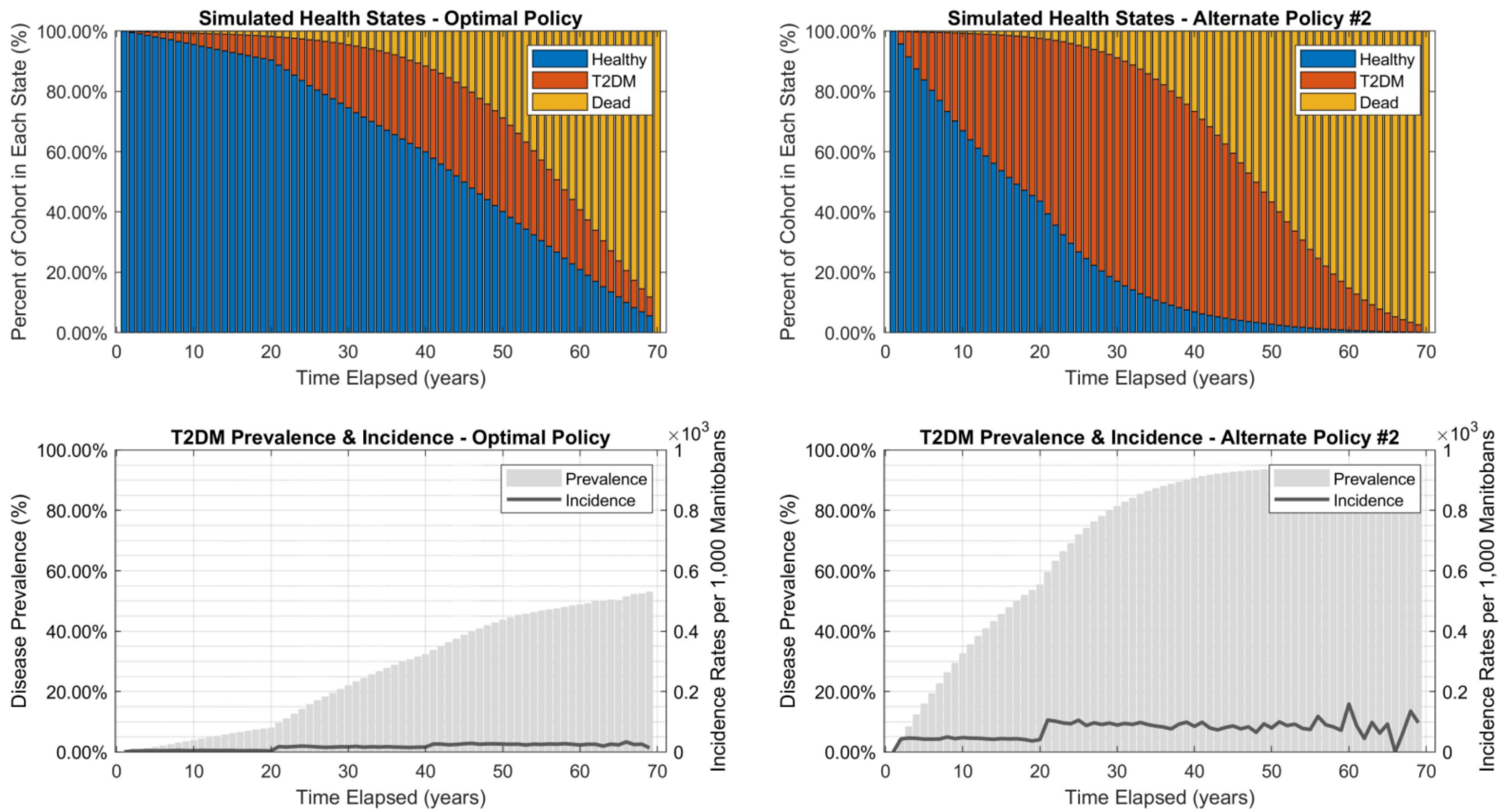

Figure 8: Projected prevalence and incidence of T2DM in Manitoba (Alternate Policy #2)

Indirect costs

Figure 9 reports indirect costs attributable to T2DM among two otherwise identical cohorts that pursue either the optimal policy or an alternate policy involving complete non-adherence to all measures available for promoting and preserving health.

As in the first scenario, losses collect at an increasing rate irrespective of which policy the cohort adopts, although they clearly accumulate much more quickly under the alternate policy. In both cases, efficiency losses decline rapidly when the cohort's members reach the standard age of retirement, although they do not abate all at once, as some individuals opt to sustain their attachment to the labour force for a few more years.

Presenteeism initially constitutes the largest proportion of indirect costs in both scenarios, although absenteeism claims an increasing share of productivity losses with the passage of time. In the optimal policy, premature mortality begins to overshadow absenteeism and presenteeism as a workplace productivity sink when cohort members are in their early 50s; in the alternate policy, by contrast, this only occurs in the years leading up to retirement. Over the entire life of the cohort, absenteeism, presenteeism and premature mortality account, respectively, for 24.2%, ($174.9 M), 23.3% ($167.9 M) and 52.5% ($379.1 M) of total indirect costs under the optimal policy, and for 32.9% ($1,238.5 M), 42.6% ($1,605.6 M) and 24.6% ($925.7 M) of costs under the alternate policy.

As in the first scenario, therefore, mortality easily accounts for the largest share of indirect costs when decision-makers pursue the optimal policy, followed by costs attributable to absenteeism and presenteeism. A markedly different result emerges from the alternate policy. While premature mortality still accounts for nearly a quarter of indirect costs (and 144.2% more than the value we observe under the optimal policy), these are now dominated by productivity losses associated with workplace absenteeism and presenteeism, both of which are roughly an order of magnitude larger for members of the cohort than when they act in a manner consistent with the solution to the dynamic optimization problem.

Total lifetime indirect costs associated with optimal and alternate policies are $721.9 M and $3,769.7 M, respectively (PV: $278.4 M and $1,623.6 M, respectively). Adopting the optimal policy is therefore associated with additional indirect costs of $3,047.8 M (PV: $1,345.3 M) when compared with a strategy involving uniform non-adherence to all health behaviours incorporated into the decision model.

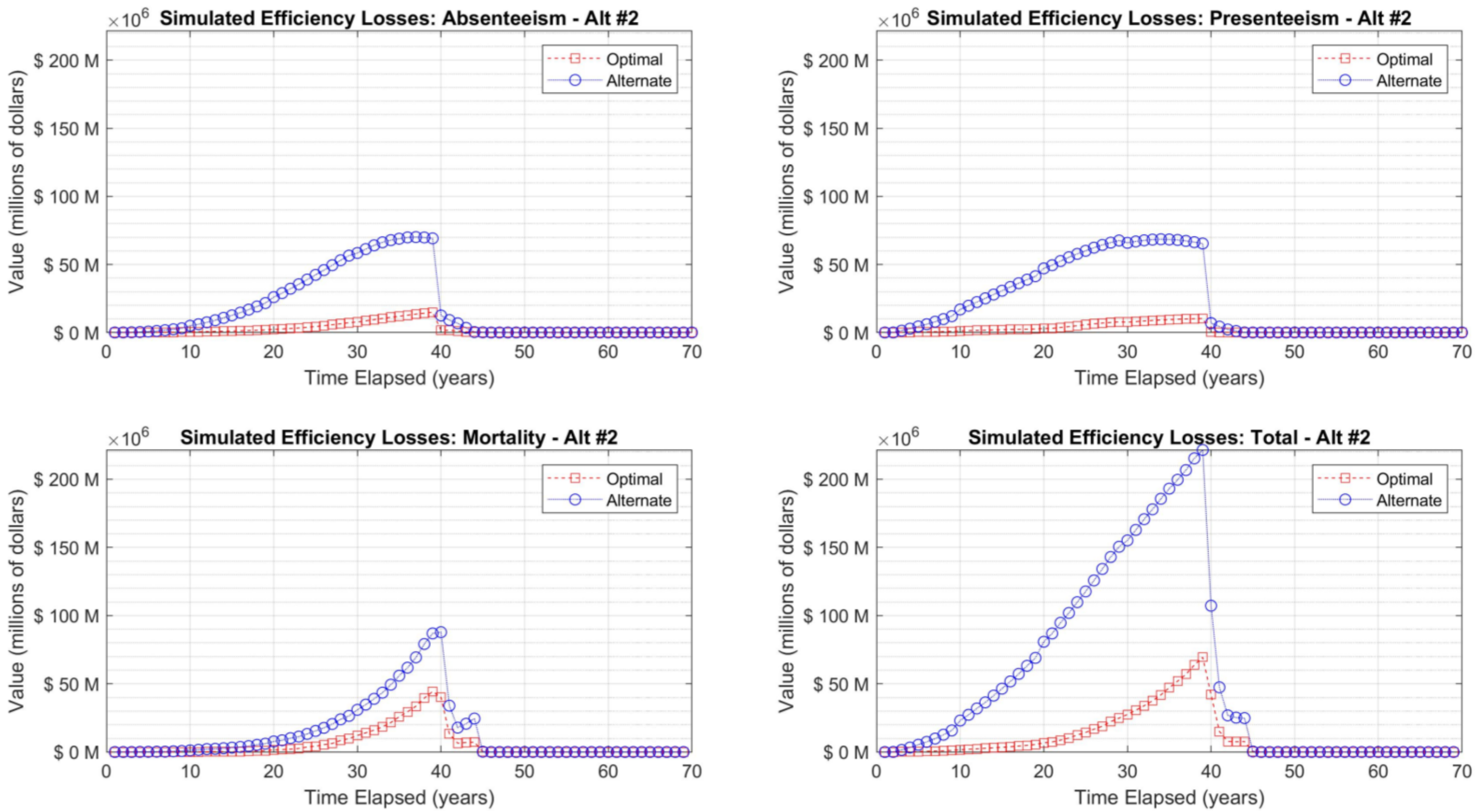

Figure 9: Projected efficiency losses attributable to T2DM in Manitoba (Alternate Policy #2)

5.3.3 Scenario 3: Optimal policy versus positive post-diagnosis behavioural shift

The third scenario once again examines variability in health and economic outcomes between two otherwise identical cohorts that respond to the risks associated with T2DM in different ways. As before, one of these cohorts faithfully adheres to the solution of the dynamic optimization problem. The second cohort in this scenario, however, adopts a more sophisticated pattern of health behaviour.

I assume that individuals who were non-adherent with physical activity and healthy eating habits when healthy react to a T2DM diagnosis by aggressively managing their condition in a manner consistent with the optimal policy. This scenario is of interest from a policy perspective, because it speaks to the extent individuals, health care practitioners and policymakers can reduce the indirect costs of T2DM by acting to carefully manage the condition rather than preventing it.

A detailed data table presenting results from the third simulation is included in Table 55 in Appendix H, which we describe in greater depth below.

Incidence and prevalence of T2DM

As shown in Figure 10, the evolution of T2DM incidence and prevalence across the two cohorts in this scenario closely mirrors the last one. Comparing Figure 9 and Figure 10, however, reveals one important difference: prevalence of T2DM is typically higher among those individuals who adopt the optimal policy upon diagnosis, after having previously chosen not to adhere to LTPA and healthy eating habits (Figure 9), than among those who act neither to prevent nor manage T2DM—despite the fact incidence of T2DM is identical across the two cohorts. This occurs because lifestyle modification initiated upon diagnosis with T2DM significantly decreases the risk of all-cause mortality among those with the condition. Consequently, those with T2DM live longer, on average, than in the last scenario and, therefore, account for a larger proportion of the population surviving to any given point in time.

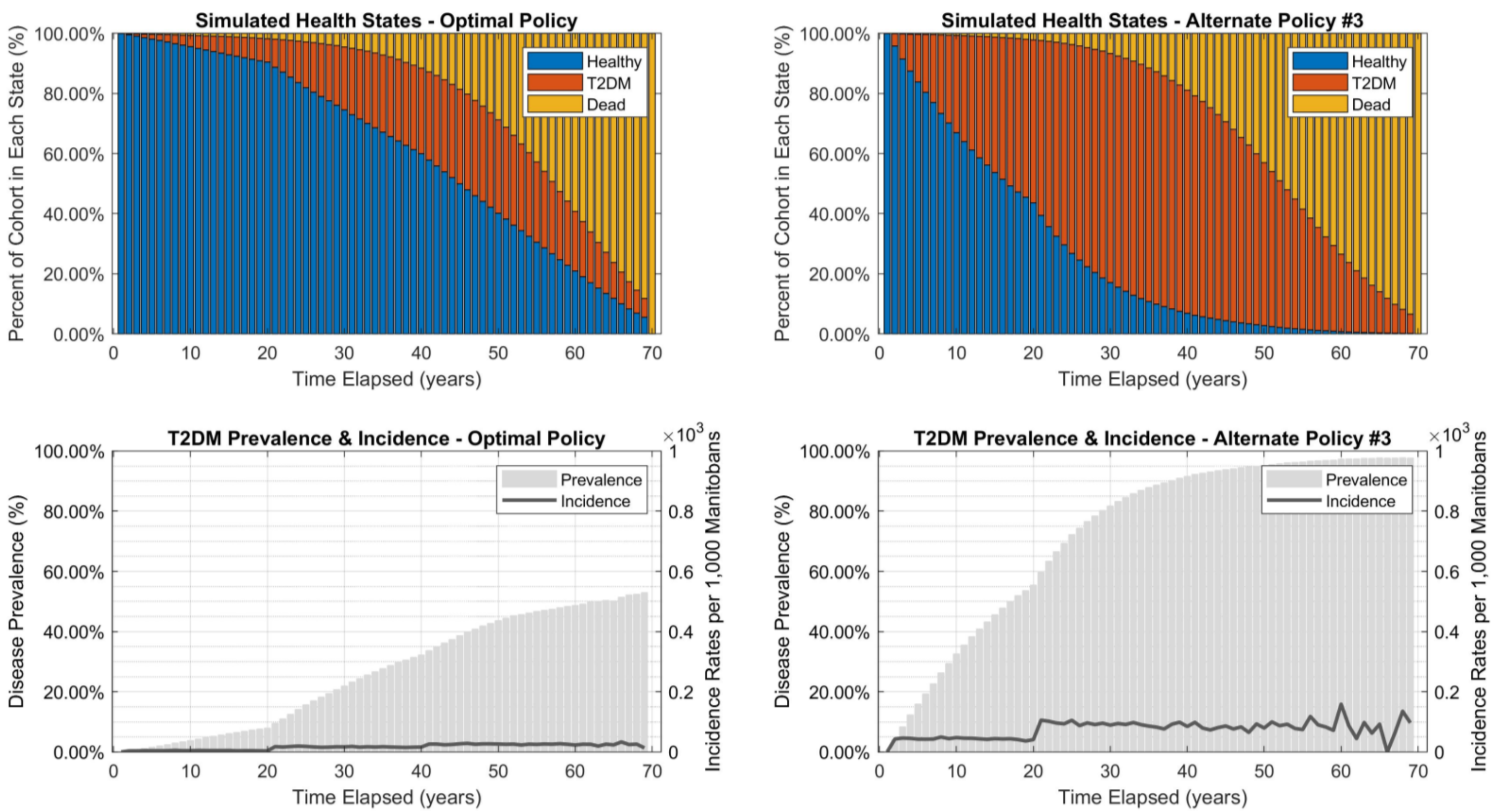

Figure 10: Projected prevalence and incidence of T2DM in Manitoba (Alternate Policy #3)

Indirect costs

Figure 11 reports indirect costs attributable to T2DM among two otherwise identical cohorts that pursue either the optimal policy or engage in positive lifestyle modification upon diagnosis with T2DM, after having been non-adherent to LTPA and healthy eating habits. Unlike Figure 7 and Figure 9, Figure 11 includes a third data series that represents costs accrued by those who never adhere to LTPA, healthy eating or pharmacotherapy. To avoid confusion, I focus here on the first two data series, deferring discussion of the third until the end.

Consistent with prior simulations, losses in the cohort accumulate steadily irrespective of the policy under consideration until the standard age of retirement, whereupon they decline precipitously and then taper off altogether as people withdraw from the labour force. However, the accumulation of losses takes place much more rapidly when people defer adoption of the optimal policy until diagnosis with T2DM, since aggressive investment in health prior to diagnosis may prevent the development of the condition in some individuals while delaying it in others.

Presenteeism initially constitutes the largest proportion of indirect costs in both cohorts, although absenteeism claims an increasing share of productivity losses with the passage of elapsed time. In the optimal policy, premature mortality begins to overshadow absenteeism and presenteeism as a workplace productivity sink when cohort members are in their early 50s; in the alternate policy, by contrast, this does not occur for several more years. Over the entire life of the cohort, absenteeism, presenteeism and premature mortality account, respectively, for 32.9% ($1,238.5 M), 42.6% ($1,605.6 M) and 24.6% ($925.7 M) of total indirect costs under the optimal policy, and for 34.9% ($814.8 M), 25.1% ($585.7 M) and 40.0% ($933.0 M) of costs under the alternate policy.

Under the alternate policy, therefore, absenteeism and premature mortality account for higher and lower shares of indirect costs resulting from T2DM, respectively, when compared to the optimal policy (the proportion of costs attributable to presenteeism is similar in both cases). In absolute terms, however, losses are invariably much higher under the alternate policy, which generates indirect costs attributable to absenteeism, presenteeism and premature mortality that are 365.8%, 248.8% and 146.1% larger than those observed when members of the simulated cohort commit to the optimal policy.

Total lifetime indirect costs associated with optimal and alternate policies are $721.9 M and $2,333.4 M, respectively (PV: $278.4 M and $980.8 M, respectively). Adopting the optimal policy is therefore associated with efficiency losses that are $1,611.5 M (PV: $702.4 M) lower when compared with a strategy involving transition from complete non-adherence to the optimal policy upon diagnosis with T2DM.

As noted earlier, Figure 11 incorporates a third data series representing indirect costs when people uniformly choose not to adhere to the health behaviours included in the model—which, to be clear, is equivalent to the alternate policy considered in Section 5.3.2 above. Overall losses observed when people manage T2DM optimally (from their perspective) despite having chosen not to invest in health prior to diagnosis lie roughly mid-way between cost levels incurred (Alternate Policy #1) when people fully commit to the optimal policy (i.e., including pre-diagnosis) and when they are never adherent to LTPA, healthy eating habits, or pharmacotherapy (Alternate Policy #2). However, losses from presenteeism under Alternate Policy #1 are closer to the optimal policy than to Alternate Policy #2, while the opposite is true of losses attributable to absenteeism. Meanwhile, losses from premature mortality associated with Alternate Policy #1 are in fact marginally higher than under Alternate Policy #2, and both are much higher than the optimal policy (i.e., 146.1% and 144.2%, respectively). Consequently, the shares of indirect costs attributable to presenteeism and premature mortality are, respectively, much lower (25.1% versus 42.6%) and higher (40.0% versus 24.6%) under Alternate Policy #1 than Alternate Policy #2. The proportion of losses linked to absenteeism is similar under both policies (34.9% versus 32.9%).

Contrasting the above figures with those presented in Section 5.3.2 indicates that a strategy involving a post-diagnosis behavioural shift from non-adherence to optimality is associated with efficiency losses that are $1,611.5 M (PV: $702.4 M) higher than adopting the optimal policy but $1,436.3 M (PV: $642.8 M) lower than employing a strategy characterized by uniform non-adherence. I discuss the implications of this finding in Section 5.3.5 below.

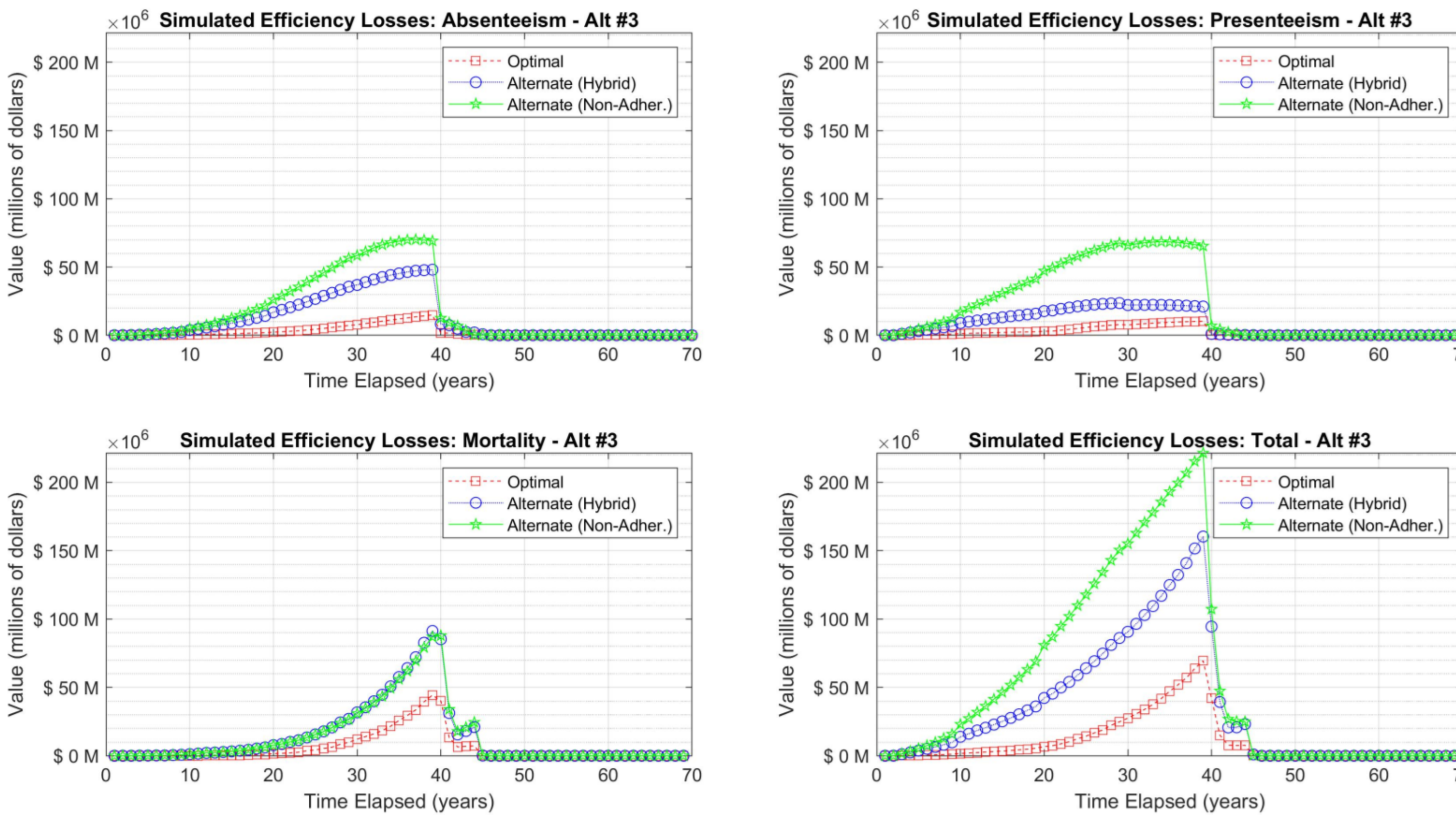

Figure 11: Projected efficiency losses attributable to T2DM in Manitoba (Alternate Policy #3)

5.3.4 Validating the results

Validating the simulation model's results is inherently challenging, as these are driven by patterns of health behaviour we do not necessarily observe in the real world. Nevertheless, comparing said results to public health statistics and prior studies can potentially produce useful insights. I begin by comparing prevalence rates predicted by the model when individuals pursue the optimal policy or choose to unconditionally adhere (Scenario 1) or not adhere (Scenario 2) to positive health behaviours (I do not include results from Scenario 3, as these closely resemble results for Scenario 2), against rates recorded for Manitoba in the Canadian Chronic Disease Surveillance System (CCDSS):

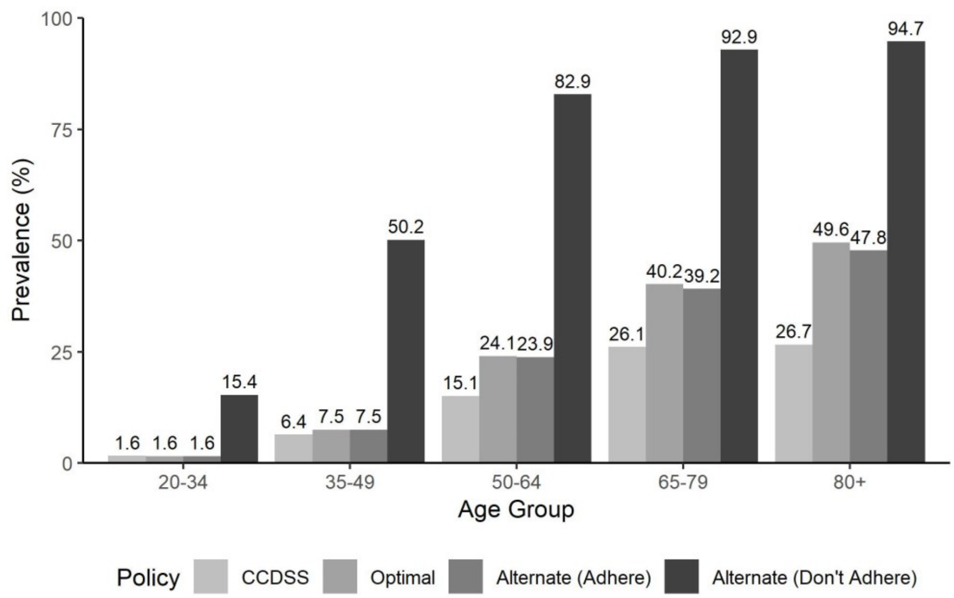

Figure 12: Comparison of prevalence, 2015-16 CCDSS Manitoba data and simulation results
Source (CCDSS data series): Public Health Agency of Canada (2018b); **Source (other):** Author calculations

As shown in Figure 12, the optimal policy and two of the alternate policies incorporated into the simulation model produce predicted prevalence rates larger than the values actually observed in Manitoba in 2015-16, which may suggest a tendency for the simulation model (and, by extension, the decision model which furnishes the transition probabilities upon which it is based) to overstate the likelihood of developing T2DM, particularly as the cohort ages.

It is important to reiterate, however—particularly with reference to the very high prevalence rates predicted for individuals adopting a strategy of total non-adherence—that because many Manitobans do of course adhere to regular physical activity, healthy eating habits and/or prescribed pharmacotherapy, the CCDSS figures are not directly comparable to the results generated by the simulation model.

I also emphasize that the CCDSS figures reflect the health of the entire Manitoba population at a point in time, while model results reflect simulated health outcomes within a cohort of individuals who were 25 years old in 2017 (see Section 5.2.2 above). To the extent Manitoba's youth are more ethnically diverse than their older counterparts, and noting that an increasing proportion of Manitobans claim ancestry from ethnic groups at higher risk of T2DM (Morency, Malenfant, & MacIsaac, 2017, p. 66), other things equal it is reasonable to assume prevalence of T2DM should be higher in these age groups in the future than it now is (Canadian Diabetes Association, 2009, p. 6).

Validation of indirect cost figures generated through the microsimulation analysis is also challenging. I identified only one prior study estimating productivity losses attributable to diabetes in this province, which was produced by the Canadian Diabetes Association (2011a) utilizing its Manitoba Diabetes Cost Model. As noted in Section 5.1.2, that study predicted total economic costs of type 1 and type 2 diabetes amounting to $639 million in 2020, including $514 million in indirect costs. The latter figure is equivalent to about $586 million in 2017 dollars.

Although the methodology underpinning the Manitoba Diabetes Cost Model is not well-documented, a published summary of findings states that the Manitoba Diabetes Cost Model draws heavily upon earlier research undertaken by the federal government in EBIC 1998 (see Section 5.1.2 above for an overview of this study), which applied a human health capital approach to calculate indirect economic costs of chronic health conditions to the Canadian economy. However, there are several important differences between that study and this one, such as the following:

- EBIC 1998 incorporates mortality costs as well as morbidity costs stemming from short- and long-term disability, but not “the value of lost production at work” (Health Canada, 2002, p. 69). Although there may be some overlap between short- and long-term disability as defined in that study and workplace absenteeism as defined in Sørensen and Ploug (2013), unlike this thesis it appears EBIC 1998 does not account for workplace presenteeism.

- EBIC 1998 clearly excludes costs linked to illness-related complications, co-morbidities, or unrelated conditions that increase health care utilization among those affected (Health Canada, 2002, p. 59). The decision model, by contrast, incorporates workplace absenteeism and premature mortality attributable to both T2DM and its complications through the structure of the UKPDS-OM2 and the parameters published in Sørensen and Ploug (2013). It may also implicitly account for presenteeism through the T2DM duration parameter published in Lavigne et al. (2003) (see Section 2.2.3 in Chapter 2).

- EBIC 1998 values unpaid work, accounts for annual growth in labour productivity, and includes productivity losses incurred in youth aged 15-24 (Health Canada, 2002, pp. 37–38). The decision model does not currently incorporate these features, which should in general result in larger indirect cost figures than we might otherwise observe.

- Perhaps most important, the EBIC 1998 indirect cost estimates are ultimately driven in part by actual health-related choices made by Canadians, whereas figures generated using the optimal and/or alternate policies are derived from the solution to the dynamic stochastic optimization problem described in Chapter 3 (which as noted below, may deviate from actual health-related decision-making in fundamental ways), or based upon behavioral patterns specified by the user.

If we conceptualize the evolution of health and economic outcomes in the cohort over the simulation horizon as a point-in-time observation of the provincial population, the overall size and composition of which is static, we can view indirect costs in the cohort as a rough approximation of annual productivity losses attributable to T2DM in Manitoba, acknowledging that neither the number nor constitution of provincial residents is, in reality, constant. From this perspective, annual indirect costs attributable to T2DM under the optimal strategy are $721.9 million. Meanwhile, costs associated with complete adherence (Scenario 1), complete non-adherence (Scenario 2), or non-adherence while healthy, followed by commitment to the optimal strategy upon diagnosis (Scenario 3) are $675.3 M million, $3,769.7 million, and $2,333.4 million, respectively.

Each of these figures, particularly the last two, is markedly larger than the estimate published by the Canadian Diabetes Association (2011a). This could suggest a tendency for the microsimulation model to overstate economic losses attributable to T2DM in Manitoba. However, any conclusion in this regard is challenged by the significant differences in the methodologies applied in their derivation.

5.3.5 Policy implications

At the beginning of this section, I noted that the limitations of dynamic stochastic optimization as a model of real-world health-related decision-making imply that microsimulation analyses undertaken using solutions to the optimization problem are not suitable for predicting actual health or economic outcomes. However, such analyses nonetheless offer important insights to guide the design and implementation of interventions, policies, and regulations aimed at preventing and managing T2DM and its complications.

Results from the second and third of the three simulations undertaken here suggest optimal adherence to healthy eating habits, regular physical activity and pharmacotherapy can significantly reduce T2DM-related indirect economic costs to the Manitoba economy. They indicate that optimal adherence within a cohort of 20,135 healthy Manitobans who were 25 years old on June 1st, 2017 produces a cost savings equal to $3,047.8 M (PV: $1,345.3 M) over the cohort's lifetime when compared to uniform non-adherence, and to $1,611.5 M (PV: $702.4 M) when compared to a strategy that involves non-adherence until diagnosis but optimal decision-making thereafter. These figures include productivity losses associated with absenteeism, presenteeism and premature mortality, but excludes other significant direct or indirect cost components (e.g., caregiving costs).

The reader should regard the first of these figures as an upper bound of the value of potential economic gains resulting from improved adherence, since many Manitobans do, of course, engage in activities intended to prevent or manage T2DM and a range of other chronic health conditions. However, the available evidence warns against overstating this point:

- Branchard et al. (2018) note that more than four in five Canadian adults possess at least one modifiable risk factor for chronic disease, noting high prevalence of physical inactivity, unhealthy eating habits, smoking, and excessive alcohol consumption.
- Recent data also suggests 61.4% of Canadian adults and 33% of children are overweight, of whom 25.4% and 13%, respectively, are obese (Standing Senate Committee on Social Affairs, Science and Technology, 2016, p. 14).

- Several studies suggest sub-optimal adherence to health-related behaviours among Canadian with diabetes (Agborsangaya et al., 2013; CIHR & CIHI, 2015; Leiter et al., 2013; Sarma, Devlin, et al., 2014; Webster, Sullivan-Taylor, & Terner, 2011).

The policy implication is straightforward: while *homo economicus* may be unattainable as a benchmark for health-related decision-making, implementing interventions, policies, and regulations that motivate Manitobans to make better choices regarding health has the potential to significantly lower the indirect costs that T2DM and other chronic diseases impose upon the provincial economy.

I noted in Section 5.1 above that comparing indirect costs associated with the two alternate policies presented in Figure 11 (page 336) can yield insight into the appropriate allocation of scarce health care system resources to T2DM prevention and management. The simulation results suggest that a cohort whose members did not act to prevent development of T2DM can nonetheless reduce efficiency losses by 38.1% (relative to not investing in healthy under any circumstances) by managing the condition in a manner consistent with the solution to the dynamic optimization problem. The implication is that a solitary focus on improved prevention or management of T2DM in Manitoba can go only so far in helping to minimize the condition's impact upon the provincial economy; rather, individuals, health care practitioners and policy-makers can only achieve this outcome through holistic approaches designed both to reduce the risk of developing T2DM and also to manage progression in those diagnosed.

Results from the first of the three simulations also offer valuable insights. For example, they imply that the incremental benefits associated with uniform adherence to LTPA, healthy eating habits and pharmacotherapy do not compensate individuals for the added costs involved in engaging in these behaviours. More specifically, optimal adherence to these behaviours within a cohort of 20,135 healthy Manitobans who were 25 years old on June 1st, 2017 is associated with added costs amounting to $46.6 M (PV: $17.5 M) over the cohort's lifetime, as compared to full adherence. Further to this, because the model assumes workers and employers share indirect costs attributable to absenteeism and presenteeism—the distribution of which the simulations do not account for—these results overstate the benefits individuals would enjoy by investing more heavily in their health.

This has two key implications. First, were individuals compelled to accept a larger share of the burden of indirect economic losses stemming from chronic disease, other things equal, we would predict greater adherence to health-related behaviours. Second, that improved prevalence and severity of chronic illness benefits not only the individual, but society more generally may serve as rationale for interventions that align their respective interests by motivating some health-related activities, while discouraging others. How this can best be accomplished is an active area of research at this time.

6. CONCLUSION

This chapter operationalizes the decision model, drawing upon the conceptual framework and parameter values outlined in Chapter 3.

Section 2 walks users through the steps required to implement the model, which exists as an integrated collection of raw data, R and MATLAB scripts, and macro-enabled Excel workbooks that are freely available to researchers from MSpace, an online research repository maintained by the University of Manitoba. The scripts gather, process, and compile data from diverse sources to furnish the inputs required to set up the dynamic optimization problem, which they then solve by applying the backward induction algorithm.

The rest of Section 2 is dedicated to interpreting the optimal policy and the value function that emerge from the solution. The model results suggest it is generally optimal for healthy decision-makers to minimize their risk of T2DM through participation in regular physical activity or adoption of healthy eating habits—but typically not both. For individuals who have been diagnosed, optimal choices following diagnosis are driven to a significant extent by a person's characteristics and circumstance, but such individuals will usually take certain steps to manage their condition.

Broadly speaking, therefore, the results suggest the detrimental impacts of T2DM on personal well-being are usually sufficient to motivate investment in health. However, people also value things besides health, and sometimes exhibit willingness to trade off a slightly increased risk of T2DM or all-cause mortality or marginally faster rate of diabetic progression for more consumption or leisure.

Section 4 describes the steps taken to validate the structure of the model and the selection of values or ranges for its parameters. These steps included thorough documentation and annotation of each script and changes thereto; adoption of automation techniques such as loop control statements and vectorization to minimize risk of human error during performance of repetitive tasks; integration of embedded checks to flag errors during the program's execution; examination of the variability of model results to changes in key parameters (i.e., sensitivity analysis); and analysis of simulated state transitions and other results produced during the microsimulation exercise. I moreover benefited from the validation measures packaged with the UKPDS-OM2 and the MDPSolve Toolbox.

The rest of Section 4 presents the results of a series of sensitivity analyses investigating the impact of changes in key model parameters. Review of the results suggests the optimal policy shifts in accordance with expectations in response to changes in preferences over, or the elasticity of substitution between consumption and leisure; the rate of time preference; the magnitude of age-related productivity decline; and, the financial cost associated with unhealthy eating habits. In addition, I carry out a series of robustness tests that investigate how the model responds to the imposition of unrealistic assumptions or the introduction of unlikely parameter values; again, the test results fully align with expectations. These results should offer a degree of assurance that the model has been correctly implemented.

Section 5 demonstrates how prospective users can integrate results generated by the decision model into microsimulation exercises to study health and economic outcomes in hypothetical patient cohorts. Such exercises cannot predict outcomes in actual patient cohorts, since Canadians' health-related choices seldom resemble those made by the fully rational, forward-looking economic agents in the decision model. However, comparing outcomes resulting from optimal and alternative strategies to address the risks posed by T2DM has significant policy relevance, because it quantifies the potential that exists to reduce the condition's impacts on the provincial economy through interventions that influence choices people make.

I illustrate one specific application of the model, namely evaluation of indirect economic costs associated with different patterns of health-related behaviour within a cohort of 20,135 Manitobans who were 25 years of age on June 1st, 2017. The analysis compared optimal health-related decision-making, with a) uniform adherence to regular physical activity, healthy eating habits, and prescribed medications; b) uniform non-adherence, and; c) uniform non-adherence among healthy individuals that shifts to optimal adherence upon diagnosis with T2DM. Compared with pursuing the optimal policy

a) uniform adherence to all health behaviours is associated with **reduced** indirect costs amounting to $46.6 M (PV: $17.5 M);

b) uniform non-adherence to all health behaviours is associated with **additional** indirect costs amounting to $3,047.8 M (PV: $1,345.3 M);

c) and, a strategy involving non-adherence while healthy and optimal adherence upon diagnosis with T2DM is associated with **additional** indirect costs amounting to $1,611.5 M (PV: $702.4 M).

Three main policy implications emerge from the microsimulation exercises:

- ❖ While the precise dollar amount is subject to uncertainty (assessing this would require information about actual health-related decision-making), health care practitioners and policymakers can potentially generate substantial cost savings for Manitobans by implementing regulations, policies, programs and interventions that motivate better health-related decisions. I reiterate that the figures presented here are limited to efficiency losses attributable to T2DM.

- Individual management of diabetes consistent with the solution to the dynamic optimization problem goes only partway towards addressing efficiency losses attributable to T2DM. Fully addressing these losses requires a comprehensive approach that encompasses both prevention and management.

- From the individual's perspective, the optimal level of expected indirect costs resulting from chronic disease over the lifespan is not necessarily zero. People value things besides health and may therefore be willing to trade off an increased likelihood of T2DM and its complications for other things that enhance their enjoyment of life, even if full-rational and forward-looking.

Chapter 5: CONCLUSION

This section concludes by discussing the strengths and potential applications of the decision model, as well as current limitations and extensions.

1. STRENGTHS

Strengths of the decision model and the approach to this research include the following:

- *Extending the ZBK model.* Despite its many strengths, the textbook ZBK model requires several modifications to satisfy the objectives of this research. These include introducing additional time periods; creating more health states and classes of states (i.e., age, T2DM duration, and history of adherence to health behaviours); and choosing state transition probabilities that are based upon or derived from the academic literature or other available resources. The decision model illustrates one viable approach to extending the ZBK model in a manner that preserves several of its fundamental features, such as the conceptualization of health dynamics as a sequence of transitions between states, and of health investment as a conscious effort to modify a stochastic process in ways that promote longevity and quality of life.

- *Examining health-related decision-making in the context of T2DM.* One important result emerging from the literature review in Chapter 2 is that few existing economic models of health-related decision-making focus on specific health conditions, and fewer still pertain specifically to T2DM.[40] The thesis addresses this gap by implementing a decision-making model that mimics the clinical characteristics of T2DM and its impact on individual well-being as faithfully as the existing data permits. That said, the framework underlying the model is sufficiently general that it could be in principle be adapted to study health-related decision-making the context of other chronic diseases.

- *Selection of parameter values appropriate to the Manitoba context.* The decision model and accompanying simulation model utilize parameter values chosen to reflect the circumstances in which Manitobans make health-related decisions as closely as possible. Where Manitoba-specific values were unavailable, Canadian values were used instead; parameters values were assumed or derived from other sources (e.g., the risk equations underlying the UKPDS-OM2) only when useable Canadian data sources could not be readily identified. For example, household pharmaceutical expenditures are derived

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40 This excludes decision analytic models commonly employed in economic evaluations of health interventions, which, other limitations notwithstanding, tend to focus on decision-making from the perspective of individuals/organizations other than the patient.

by assuming the existence of a provincial drug benefit program resembling Manitoba's Pharmacare Program. Similarly, the size of the starting cohort for the simulation analyses is based upon administrative data collected by Manitoba Health, Seniors and Active Living (2018b), although its composition is based upon national statistics from the 2011 NHS PUMF.

- *Integration of dynamic optimization and microsimulation modelling.* This study integrates the decision model with a simple microsimulation model, enabling the user to compare efficiency losses incurred by a hypothetical patient cohort (consisting here of a cohort of 20,135 Manitobans who were 25 years old in 2017) when people behave in a manner consistent with the solution to the dynamic optimization problem, versus when they adopt an alternate approach to the prevention and/or management of T2DM. Prospective users could easily modify or extend the model to examine health and economic outcomes experienced by patient cohorts different than the one studied here, or to account for other outcomes of interest, such as direct costs.

- *Steps to promote accessibility and transparency.* The author took the following steps to ensure the products of this research can be accessed, understood, applied and extended by as many users as possible:

- All scripts and relevant materials developed by the author are downloadable from MSpace (see Section E.2 below for a permanent hyperlink) or available from the author upon request.

- All scripts are thoroughly annotated to help users understand how the code works, and what it is intended to accomplish. Moreover, the decision model comes packaged with a user guide (included in Appendix E and also available from MSpace) that walks the reader through the sequence of steps required to solve the dynamic optimization problem and implement microsimulations using the results. To supplement this, I have prepared an online demonstration, accessible at https://youtu.be/1u50_bkacx0, which is intended to perform a similar function.

- R (including the add-on packages referenced in Appendix E), which is used for the bulk of the calculations, can be costlessly downloaded from the Comprehensive R Archive Network mirror located on the website of the Manitoba UNIX User Group (2018). MATLAB, which is used to solve the decision model, is proprietary software; however, the program which implements the backward induction algorithm in MATLAB is freely available from a website maintained by Paul Fackler (2014).

- The scripts accompanying the model include all operations necessary to extract needed information from the original Statistics Canada NHS and SLID PUMFs, meaning the latter need not be manipulated prior to use.

- Web scraping techniques are applied in several instances, enabling any user with Internet access to automate the collection of key sources of information serving as the basis for values for parameters incorporated into the model. This is especially useful when website content is regularly updated, because it ensures the model remains current.

- The integrated microsimulation model carefully manages random number generation to ensure the user can readily reproduce the results presented in Section 5 of Chapter 4.

2. POTENTIAL APPLICATIONS

The decision model developed through this research and described in this thesis has at least two potential applications:

- *Contributing to our understanding of optimal health-related decision-making.* Building upon prior studies by Grossman (1972), Zweifel et al. (2009), and many others, this research offers a framework for exploring how fully-rational, forward-looking decision-makers make choices that impact health when health and employment state transitions occur randomly. It furthermore furnishes researchers with tools to examine how optimizing behaviour varies with an individual's personal characteristics and life circumstances.

- *Facilitating calculation of direct and/or indirect costs reductions achievable through lifestyle modification, in the context of chronic disease.* Patient-level microsimulation modelling enables the user to investigate how health-related decisions influence T2DM incidence and prevalence and impact the provincial economy. Researchers and policymakers can use, modify or extend the model developed through this research to predict incremental direct and indirect costs attributable to deviation from optimal health-related decision-making. In principle, the microsimulation model can also be configured to study how two distinct sets of optimal policies compare with one another (e.g., optimal choices under the status quo, versus an existing, emerging, or hypothetical intervention for T2DM). In its current formulation, the model is a proof of concept which, with further development and investment, could produce information of value to researchers and policymakers.

3. LIMITATIONS

The decision model incorporates a range of features which improve realism, but which also introduce challenges in relation to selecting appropriate parameter values and satisfying the computational demands necessary for implementation. Recognizing this, the author chose to introduce a series of assumptions and simplifications that may limit the model's ability to contribute to achieving the goals of this research. The most significant of these are as follows:

- *Reliance upon the assumption of full rationality and complete information.* While foundational to this research, the assumption that individuals are unfailingly rational and possess both the mental capacity and knowledge required to accurately evaluate the likely implications of their actions is difficult to reconcile with a growing body of evidence suggesting significant limitations to people's capacity to collect, process, and apply information. Although this study failed to identify alternative models of health-related decision-making sufficiently well-developed, widely accepted, and otherwise suitable for achieving the objectives of this research, continual advancements in behavioural economics and related disciplines may one day conceivably furnish these (Shin & Roh, 2019).

- *Modelling asset accumulation and decumulation.* This is challenged by the memorylessness of MDPs, which makes it difficult to keep track of how much has been saved or is owed at any time. The model circumvents this issue by assuming a fixed proportion of employment income is deposited in a retirement fund accessible beginning at age 65. This implies, however, that individuals have no discretion over saving and borrowing. Fundamental changes in the modelling approach would likely be required to address this.

- *Single-unit households.* The model assumes all households are comprised of a single adult, which effectively sidesteps issues relating to the influence of other household members on the individual's choices or resources. While most health-related decision-making is probably made within the context of multi-unit households, this would be very difficult to accommodate given the wide range of possible household configurations.

- *No comorbidities or concurrent health conditions.* The model effectively assumes a world consisting of a single chronic disease, excepting microvascular and macrovascular complications linked directly to T2DM. In reality, comorbidities are common among individuals with diabetes (American Association of Endocrinologists, 2019; Finlayson et al., 2010; Piette & Kerr, 2006). Further to this, it should be recognized that many diabetic complications can be or are often conceptualized as distinct comorbidities that constitute part of the same overall pathophysiological risk profile (Piette & Kerr, 2006, p. 727):

- The model does not presently account for "discordant" conditions not closely related to the pathogenesis or management of T2DM, such as arthritis, depression and asthma (p. 727). Although the framework presented in this thesis does not fundamentally preclude consideration of one or more of these comorbidities—it can in principle accommodate an arbitrarily large number of states—accounting for all possible combinations of comorbid conditions would likely require a substantial investment in data development and would significantly increase the volume of computational resources required to initialize and the solve the decision problem. In the immediate term, however, it may, be possible to extend the model to account for a subset of discordant comorbidities of especial interest.

- By contrast, while this study does not explicitly model "concordant" conditions such as hypertension, hyperlipidemia and peripheral arterial disease (An et al., 2019, p. 66; Piette & Kerr, 2006, p. 727)—there are not, for instance, distinct states for T2DM patients with hypertension—it does account for them implicitly through the UKPDS-OM2 risk equations. In the case of hypertension, for example, SBP is seen to influence the risk of experiencing a range of diabetic complications (i.e., IHD, 1st MI and stroke, blindness, 1st ulcer, and renal failure). While it may be preferable to render these relationships explicit, this could require effectively recreating the UKPDS-OM2 within the decision model—an exercise which would entail confronting many of the challenges outlined in the previous point.

- *Restrictions on the frequency with which decisions can be taken.* The optimization model imposes restrictive assumptions regarding the timing of decisions:

  - The model assumes individuals with T2DM can revisit their decision to adhere to LTPA, healthy eating habits and compliance with pharmacotherapy at most twice—immediately upon diagnosis and again one decade later. While progression of T2DM likely depends on an individual's entire history of health-related decisions, reflecting this in the structure of the decision model causes the number of model states to grow exponentially. For instance, 738 distinct states currently represent the first decade with T2DM for individuals aged 27-35 (see Table 2 on page 93). Were individuals able to revisit their choices during each of these years, the number of states would increase to 2.79×10^{232}; it is not feasible at the present time to satisfy the enormous memory requirements this would entail. That said, it may be possible to include additional choice "milestones" that enable patients to revise their health-related decisions with greater frequency.

- More generally, the model assumes annual decision epochs, which is to say decisions of any kind can be made only at the beginning of each year. While imposing no restriction on the timing of choices (e.g., continuous-time Markov processes) would require fundamental changes to the model structure, the model could be modified to increase the frequency of epochs, thereby enabling choices to be made (for example) on a monthly basis. However, in applying such a modification one would likely confront the same issue described in previous point—namely, that the explicit modeling of age and T2DM duration implies that greater discretion over the timing of the decisions would cause the number of model states to expand rapidly. It is possible increasing the frequency of decision epochs would generally add only modest incremental value—perhaps excepting specific sub-groups, such as patients whose health is deteriorating rapidly due to the accumulation of diabetic complications.

It is essential to reiterate, as suggested above, that the decision model and microsimulation model each represent a proof of concept, serving primarily to illustrate the potential of the methods outlined in this thesis to advance our understanding of optimizing behaviour in the context of chronic disease, as well as to inform the design and implementation of interventions that improve health and economic outcomes for Manitobans by influencing health-related decision-making. This is best exemplified by its reliance upon results generated by the United Kingdom Prospective Diabetes Study Outcomes Model, Version 2 (UKPDS-OM2), whose originators explicitly warn against extrapolating results to populations other than those included in the UKPDS (University of Oxford Diabetes Trials Unit & Health Economics Research Centre, 2015, p. 2); further to this, the UKPDS did not include individuals of Indigenous ancestry (i.e., Inuit, Métis and First Nations), who are known to be at especially high risk for both T2DM and its complications (Crowshoe et al., 2018, pp. S297–S298).

My expectation is that future research can overcome the limitations described above, and that so doing will enable the model's potential to be fully realized. Further to the issue just described, for example, compilation of predictive risk equations analogous to those underpinning the UKPDS-OM2 using Manitoba-specific administrative data would help to ensure transition probabilities derived therefrom accurately represent the unique characteristics of the provincial population.

4. EXTENSIONS

Future research can improve upon the model by addressing one or more of the limitations outlined in the previous section. It can also extend the model in a variety of ways. Specific examples include the following:

- *Modifying assumptions regarding health state observability.* Whereas the model now assumes decision-makers are always fully cognizant of their state of health, future variants could examine how patient decision-making and health outcomes vary when their health state is unknown to them or only partially observable, although this would require more sophisticated modelling techniques than I applied in this thesis (Littman, 2009, p. 120). Given that patients with prediabetes or in the early stages of T2DM are often asymptomatic, this could represent a fruitful area for future research.

- *Greater flexibility around modelling employment state transitions.* Another implication of the memorylessness of the model is difficulty capturing phenomena relating to duration of unemployment, such as scarring (e.g., recovering employment becomes harder the longer one is unemployed) or eligibility for EI programming. It is certainly possible to track duration of unemployment by expanding the number of model states. As noted elsewhere, however, this has the potential to increase the level of computational effort required to set up and solve the dynamic optimization problem.

- *Improved household food and pharmaceutical expenditure figures.* There are several opportunities to refine household spending figures as they relate to food and medication:

    - The model presently derives T2DM medication costs with reference to a small number of "profiles" that reflect prior management and duration of T2DM. Developing and costing more treatment scenarios could promote model realism. The model could also be adapted to explore how availability of private health insurance or modifications to the Pharmacare program affect adherence to pharmacotherapy.

    - The food costing exercise could be enhanced by accounting for variability in the prices of food and beverages over time and across the province; by extending the exercise to include alcoholic beverages and food prepared and/or consumed outside the home; and, by acquiring data on Manitobans' food and beverage purchasing habits.

- *Enhancing the design and implementation of the decision model and microsimulation model.* I believe the decision model and microsimulation model could be improved in one or more of the following ways:

  - Both models require at least some programming knowledge to operate and a significant level of expertise to modify. Incorporating intuitive user interfaces or programming all components in R or MATLAB (or integrating the scripts in such a way that the models can be operated from one of the two software environments) could help promote ease of use.

  - Whereas this thesis focused on indirect costs attributable to T2DM, the decision model could be configured to output direct costs associated with each state through modification to the UKPDS-OM2, which could then be integrated into the microsimulations.

  - A natural focus for future research would be to simulate direct and/or indirect costs for the population of Manitoba as a whole, rather than the small subset considered in this thesis. Further enhancements might include incorporating provincial in- and out-migration and fertility; modifying the starting cohort to account for cases of T2DM emerging during childhood/ adolescence and young adulthood; and, incorporating data regarding actual health behaviour among Manitobans. These changes would allow prospective users to more precisely calculate productivity losses resulting from sub-optimal health-related decision-making in the Province of Manitoba.

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APPENDIX A: NET EMPLOYMENT INCOME, FOR HEALTHY FULL- AND PART-TIME WORKERS

Table 30: Net employment income by gender, age, level of educational attainment, healthy full-time workers (2017 current dollars)[1]

Age	No certificate, diploma or degree		High school diploma or equivalent		Post-secondary certificate or diploma below bachelor level		University certificate, diploma, or degree at bachelor level or above	
	Male	Female	Male	Female	Male	Female	Male	Female
25-34	$25,822	$21,825	$29,093	$23,847	$33,675	$26,476	$36,527	$36,863
35-44	$29,093	$24,513	$34,924	$25,822	$38,881	$30,401	$51,438	$47,958
45-54	$33,675	$24,513	$36,191	$29,093	$41,570	$31,709	$55,817	$48,935
55-64	$29,093	$23,173	$33,018	$29,747	$42,579	$31,709	$55,817	$51,438
65	$46,830	$36,428	$47,161	$36,792	$58,132	$45,583	$76,223	$69,102
66	$46,241	$35,948	$46,630	$36,346	$57,456	$44,960	$75,226	$68,136
67	$45,651	$35,468	$46,100	$35,899	$56,780	$44,337	$74,228	$67,170
68	$45,062	$34,961	$45,570	$35,453	$56,104	$43,714	$73,230	$66,204
69	$44,473	$34,438	$45,039	$34,966	$55,428	$43,091	$72,232	$65,238
70	$43,883	$33,914	$44,509	$34,479	$54,753	$42,468	$71,234	$64,272
71	$43,294	$33,390	$43,978	$33,992	$54,077	$41,845	$70,236	$63,271
72	$42,705	$32,866	$43,448	$33,506	$53,401	$41,222	$69,239	$62,211
73	$42,115	$32,343	$42,918	$33,019	$52,725	$40,599	$68,241	$61,185
74	$41,526	$31,819	$42,387	$32,532	$52,049	$39,976	$67,275	$60,209
75	$40,937	$31,295	$41,857	$32,045	$51,373	$39,353	$66,365	$59,235
76	$40,347	$30,771	$41,327	$31,558	$50,698	$38,730	$65,457	$58,288
77	$39,758	$30,248	$40,796	$31,071	$50,022	$38,107	$64,575	$57,340
78	$39,169	$29,724	$40,266	$30,584	$49,303	$37,484	$63,654	$56,392
79	$38,580	$29,200	$39,735	$30,097	$48,570	$36,861	$62,675	$55,445
80	$19,515	$28,677	$17,859	$29,610	$23,536	$36,238	$32,522	$54,497
81	$18,853	$28,153	$17,263	$29,123	$22,713	$35,615	$31,364	$53,549
82	$18,190	$27,629	$16,667	$28,636	$21,890	$34,935	$30,207	$52,602
83	$17,528	$27,105	$16,071	$28,149	$21,067	$34,255	$29,049	$51,654
84	$16,866	$14,283	$15,475	$13,488	$20,243	$17,661	$27,891	$27,120

Table 30: Net employment income by gender, age, level of educational attainment, healthy full-time workers (2017 current dollars)[1]								
Age	**No certificate, diploma or degree**		**High school diploma or equivalent**		**Post-secondary certificate or diploma below bachelor level**		**University certificate, diploma, or degree at bachelor level or above**	
	Male	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**
85	$16,204	$13,744	$14,879	$12,987	$19,420	$16,960	$26,734	$25,999
86	$15,541	$13,204	$14,283	$12,485	$18,597	$16,260	$25,576	$24,878
87	$14,879	$12,665	$13,687	$11,984	$17,774	$15,560	$24,416	$23,735
88	$14,217	$12,126	$13,091	$11,483	$16,951	$14,860	$23,224	$22,580
89	$13,555	$11,587	$12,495	$10,981	$16,128	$14,160	$22,032	$21,426
90	$12,892	$11,047	$11,899	$10,377	$15,305	$13,460	$20,840	$20,272
91	$12,230	$10,411	$11,303	$9,764	$14,482	$12,760	$19,647	$19,118
92	$11,568	$9,752	$10,654	$9,151	$13,659	$12,060	$18,455	$17,963
93	$10,897	$9,093	$9,926	$8,486	$12,836	$11,360	$17,263	$16,809
94	$10,088	$8,369	$9,197	$7,794	$12,012	$10,596	$16,071	$15,655

[1] Figures for individuals younger than 65 include amounts set aside for retirement, which accumulate at a fixed rate. Beginning at age 65 and continuing for a duration corresponding to the average life expectancy of each gender, fixed amounts are withdrawn from accumulated savings until the latter are depleted, whereupon decision-makers must subsist on employment income alone.

Source: Canada Revenue Agency (2017b, 2017c); EY (2018); Statistics Canada (Statistics Canada, 2016, 2017c, 2018c)

Table 31: Net employment income by gender, age, level of educational attainment, healthy part-time workers (2017 current dollars)[1]

Age	No certificate, diploma or degree		High school diploma or equivalent		Post-secondary certificate or diploma below bachelor level		University certificate, diploma, or degree at bachelor level or above	
	Male	Female	Male	Female	Male	Female	Male	Female
25-34	$13,001	$11,229	$14,478	$12,115	$16,546	$13,297	$17,875	$18,023
35-44	$14,478	$12,411	$17,137	$13,001	$18,909	$15,069	$24,505	$22,897
45-54	$16,546	$12,411	$17,728	$14,478	$20,091	$15,660	$26,512	$23,340
55-64	$14,478	$11,820	$16,251	$14,774	$20,534	$15,660	$26,512	$24,505
65	$34,968	$26,058	$36,553	$27,175	$44,176	$32,895	$56,803	$49,752
66	$34,646	$25,796	$36,288	$26,931	$43,810	$32,555	$56,313	$49,239
67	$34,324	$25,532	$36,012	$26,688	$43,443	$32,215	$55,824	$48,725
68	$34,003	$25,263	$35,723	$26,444	$43,077	$31,875	$55,334	$48,212
69	$33,681	$24,993	$35,433	$26,201	$42,711	$31,535	$54,845	$47,698
70	$33,360	$24,724	$35,144	$25,957	$42,345	$31,196	$54,356	$47,185
71	$33,038	$24,454	$34,854	$25,713	$41,979	$30,856	$53,866	$46,671
72	$32,717	$24,184	$34,565	$25,462	$41,612	$30,516	$53,377	$46,158
73	$32,395	$23,915	$34,275	$25,211	$41,246	$30,176	$52,887	$45,644
74	$32,073	$23,645	$33,986	$24,960	$40,880	$29,836	$52,398	$45,130
75	$31,752	$23,375	$33,697	$24,710	$40,514	$29,496	$51,909	$44,617
76	$31,430	$23,106	$33,407	$24,459	$40,147	$29,156	$51,419	$44,103
77	$31,109	$22,836	$33,118	$24,208	$39,781	$28,816	$50,930	$43,590
78	$30,787	$22,566	$32,828	$23,958	$39,415	$28,476	$50,435	$43,076
79	$30,465	$22,297	$32,539	$23,707	$39,049	$28,136	$49,904	$42,563
80	$11,237	$22,027	$10,290	$23,456	$13,247	$27,796	$17,859	$42,049
81	$10,897	$21,757	$9,926	$23,205	$12,836	$27,456	$17,263	$41,536
82	$10,492	$21,488	$9,562	$22,955	$12,424	$27,116	$16,667	$41,022
83	$10,088	$21,218	$9,197	$22,704	$12,012	$26,776	$16,071	$40,509
84	$9,683	$7,996	$8,820	$7,447	$11,601	$10,169	$15,475	$15,078
85	$9,278	$7,624	$8,408	$7,101	$11,189	$9,741	$14,879	$14,501
86	$8,865	$7,251	$7,996	$6,754	$10,741	$9,313	$14,283	$13,924
87	$8,408	$6,879	$7,584	$6,408	$10,238	$8,878	$13,687	$13,346
88	$7,950	$6,506	$7,173	$6,062	$9,735	$8,395	$13,091	$12,769
89	$7,493	$6,134	$6,761	$5,715	$9,232	$7,911	$12,495	$12,192

Table 31: Net employment income by gender, age, level of educational attainment, healthy part-time workers (2017 current dollars)[1]								
Age	**No certificate, diploma or degree**		**High school diploma or equivalent**		**Post-secondary certificate or diploma below bachelor level**		**University certificate, diploma, or degree at bachelor level or above**	
	Male	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**
90	$7,035	$5,761	$6,349	$5,369	$8,702	$7,428	$11,899	$11,615
91	$6,578	$5,388	$5,937	$5,023	$8,133	$6,944	$11,303	$11,038
92	$6,120	$5,016	$5,526	$4,676	$7,565	$6,460	$10,654	$10,353
93	$5,663	$4,643	$5,114	$4,330	$6,996	$5,977	$9,926	$9,648
94	$5,206	$4,271	$4,702	$3,983	$6,428	$5,493	$9,197	$8,943

1 Figures for individuals younger than 65 include amounts set aside for retirement, which accumulate at a fixed rate. Beginning at age 65 and continuing for a duration corresponding to the average life expectancy of each gender, fixed amounts are withdrawn from accumulated savings until the latter are depleted, whereupon decision-makers must subsist on employment income alone.

Source: Canada Revenue Agency (2017b, 2017c); EY (2018); Statistics Canada (Statistics Canada, 2016, 2017c, 2018c)

APPENDIX B: FOOD COSTING EXERCISE

B.1 RATIONALE FOR THE SELECTED APPROACH

The methodology outlined here, key results of which are presented in Chapter 3 (Section 3.5.1 [page 114]), is motivated by the absence of recent studies determining the level of expenditure required to consume diets of varying levels of quality in the Province of Manitoba.

B.2 METHODOLOGY

The exercise involved the following steps, each of which is described in greater detail below:

- I identified two diets that could be considered representative of healthy and unhealthy eating habits. The first diet was defined with reference to the first week of recipes in the Winnipeg Regional Health Authority (2010) *Four Weeks of Healthy Menus*, while the second was based upon my own consumption of all food and beverages over a defined period.

- I evaluated the quality of each diet using

- the Canadian Nutrient File (CNF) 2015, a computerized food composition database developed by Health Canada that records average nutrient values in foods in Canada (Deeks, Verreault, Klutka, & Cheung, 2016, p. 1);
- and, the AHEI-2010, a 110-point index developed by Chiuve et al. (2012, p. 1010) that summarizes how well a person eats (i.e., as this relates to their risk of chronic disease) by assessing the extent to which they eat enough of certain food items and nutrients and too much of others.

❖ I calculated the cost of each diet using prices collected from the website of a large Canadian supermarket chain (Loblaw's Inc., 2019).

❖ I used the results yielded through this exercise to predict the expenditures required to maintain diets characterized by very low and very high AHEI-2010 scores for individuals with varying levels of caloric intake.

B.2.1 DEVELOPMENT OF THE REFERENCE DIETS

This objective was achieved by extrapolating from two "reference diets" that vary widely in terms of the quantity and quality of foods and beverages consumed.

The first diet (hereafter, "Diet A") was defined with reference to the Winnipeg Regional Health Authority's (2010) *Four Weeks of Healthy Menus*, which is in turn based upon *Canada's Food Guide* (page 5). The first week of recipes was used as the basis for the costing exercise.[41] These and other recipes in the document are designed to meet the dietary needs of a single adult woman aged 19-50, including those with diabetes and heart disease. The document is well-suited for this exercise because it includes detailed lists of all items found in the menus, including the quantities and volumes in which they would typically be purchased.

The second diet (hereafter, "Diet B") was generated by recording the author's own consumption of all food and beverages at or away from home during the week of September 24th-30th, 2017. To facilitate this process, the weight of most solid food items was measured using a digital kitchen scale, while measuring cups were utilized to determine the volume of any liquid (except water) consumed. For food and beverages consumed outside the home. In these instances, the author applied personal judgement to assess the contribution of each component to the item's overall weight.

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41 A single change was made to promote comparability between the two diets. It was assumed that the individual adopting Diet A would consume coffee (including a small amount of 2% milk) with the same frequency as the author did over the week in question. This change would not have significantly affected the AHEI scoring, since coffee contains negligible amounts of the nutrients incorporated into the index, nor does it count towards consumption of any of the food types tracked.

B.2.2 EVALUATION OF DIETARY QUALITY

As noted in Chapter 3, evaluation of eating habits was undertaken using the Alternative Healthy Eating Index 2010 (AHEI-2010), a tool developed by Chiuve et al. (2012) that assesses dietary patterns—as opposed to specific nutrients or foods—with reference to their influence on the risk of chronic disease.

The AHEI-2010 is a 110-point index that awards higher scores for greater consumption of fruit, vegetables, nuts and legumes, whole grains, eicosapentaenoic and docosahexaenoic acids (EPA and DHA, respectively—both types of omega-3 fatty acid), and polyunsaturated fatty acids (PUFAs), and for lower consumption of trans fats, alcohol (since some studies suggest moderate use reduces chronic disease risk, maximum points are awarded for low but non-zero levels of consumption), red and processed meats, sugar-sweetened beverages and fruit juices, and sodium. A maximum of ten points may be awarded within each category.

Several AHEI-2010 scoring components (i.e., vegetables, fruit, nuts and legumes, whole grains, alcohol, red and processed meat, and sugar-sweetened beverages and fruit juice) can be derived simply by recording the quantity of each item consumed during a particular period, which can then be converted into servings using the conversions included in Chiuve et al. (2012, p. 1010). However, detailed data on the nutritional composition of specific food products was required to calculate consumption of EPA and DHA, PUFAs, trans fats, sodium, and overall caloric intake. This information was acquired from the Canadian Nutrient File (CNF), 2015, a computerized food composition database developed by Health Canada that records average values of nutrients in foods available in Canada (Deeks et al., 2016, p. 1).

Details regarding the extraction and conversion of CNF-2015 data directly pertinent to the AHEI-2010 scoring process are presented in Table 32. Since nutrient values in the CNF-2015 are presented in terms of 100 g of the edible portion of the food,[42] the recorded quantities of all items included in both meal plans were converted into grams, as necessary:

Table 32: Data extraction and processing for AHEI-2010 components

Component	Unit	Description of data extraction and processing steps
1. Total vegetables (excludes potatoes)	Servings/day	Described in the text.
2. Total fruit	Servings/day	
3. Nuts and legumes	Servings/day	
4. Whole grains	g/day	Because foods can vary widely in their content of whole grains, the author collected data on the whole grains found in several selected items bearing the Whole Grain Stamp (The Whole Grains Council, 2017). The content of all items not found in the list itself was determined by applying the average across items it included.

42 Generally speaking, the recorded quantities in the author's meal plan included only edible portions; that is, the author tended to consume the entire amount of each food listed.

Table 32: Data extraction and processing for AHEI-2010 components		
Component	**Unit**	**Description of data extraction and processing steps**
5. EPA + DHA	mg/day	EPA and DHA associated with each item in the CNF-2015 are recorded under Nutrient Codes 629 and 621, respectively. As both nutrients are already recorded in grams in the database, consumption was multiplied by 1,000 to convert into milligrams.
6. PUFA	% of energy	Total PUFAs associated with each item in the CNF-2015 are recorded under Nutrient Code 646, while energy is recorded under Nutrient Code 208. However, PUFAs are recorded in grams while energy is expressed in kilocalories (kcal); therefore, the former was converted into kilocalories by applying the Atwater general factor system coefficient of 9.0 kcal/g for fats (United Nations Food and Agriculture Organization, 2003, p. 23). It should be noted that calorie values in the CNF-2015 utilize Atwater factors specific to described food types (Deeks et al., 2016, p. 7).
7. Trans fat	% of energy	Total trans fats associated with each item in the CNF-2015 are recorded under Nutrient Code 605, while energy is again recorded under Nutrient Code 208. The same conversion process applied to PUFAs was also applied to trans fats.
8. Alcohol	Drinks/day	Not included in the analysis.
9. Red and processed meat	Servings/day	Described in the text.
10. Sugar-sweetened beverages and fruit juice	Servings/day	
11. Sodium	Decile (mg/day)	The sodium content of each item in the database is recorded under Nutrient Code 307. As sodium is already recorded in milligrams in the database, no unitary conversions are required. The deciles used as the basis for AHEI scoring are based on weighted averages derived for Canada by Tanase, Koski, Laffey, Cooper, and Cockell (2011), which are in turn drawn from 35,000 dietary recalls from Cycle 2.2 of the CCHS.

B.2.3 EVALUATION OF CALORIC INTAKE

The AHEI-2010 does not directly rate caloric consumption, although overall energy intake indirectly affects the scores associated with two components of the index (i.e., PUFAs and trans fats). To ensure the costing exercise accounted for both the quality and amounts of food and beverages consumed, both diets were "scaled" to reflect the levels of caloric intake required to sustain stable body weights for individuals of both genders and varying ages, ethnicities, and levels of physical activity.

This information, which is presented in Table 33, was derived from the estimated energy requirement (EER) formulas developed by the Institute of Medicine using the approach outlined in Section 3.6.1 in Chapter 3 (page 156) (Otten et al., 2006). Ratios of these values to caloric intake associated with the healthy and unhealthy diets (2308.33 and 1977.97 *kcal*, respectively) were then applied to the quantity of each item consumed in both diets.

Table 33: EERs for healthy and unhealthy diets, by gender, age and ethnicity

Age	Diet	Afro-Caribbean		Asian-Indian		Caucasian	
		Male	Female	Male	Female	Male	Female
25-44	Healthy	2,452.32	1,891.69	2,342.01	1,806.80	2,465.15	1,890.26
	Unhealthy	2,974.95	2,365.64	2,837.06	2,257.82	2,990.99	2,363.82
45-64	Healthy	2,233.13	1,732.76	2,122.82	1,647.87	2,245.96	1,731.33
	Unhealthy	2,755.76	2,206.71	2,617.87	2,098.89	2,771.80	2,204.89
65-94	Healthy	1,990.11	1,556.55	1,879.81	1,471.66	2,002.94	1,555.13
	Unhealthy	2,512.74	2,030.50	2,374.86	1,922.69	2,528.78	2,028.69

Source: Author's calculations, based upon sources cited in text

B.2.4 DIETARY COSTING

Most cost data were collected from the website of a large Canadian supermarket chain (Real Canadian Superstore®) during April 2017 and reflect the prices in effect at that time. Slightly different approaches were applied to facilitate costing of the two reference diets.

- *Diet A.* Since the Winnipeg Regional Health Authority (2010) document does not recommend specific brands, costing was undertaken by applying the following guidelines:
  - Apply prices associated with the largest quantity/volume in which each product is sold.
  - Apply prices associated with easily recognizable brands, and do not select organic foods.
  - Select whole grain, calorie-reduced, low-fat/fat-free, and sodium-reduced items wherever possible (Diet A).
- *Diet B.* The author recorded the brands of each product he consumed. These same brands were used as the basis for the costing exercise if sold by the supermarket chain. If not marketed through this chain, the author identified similar products to serve as proxies. For foods the author consumed but did not personally prepare (e.g., at restaurants), he identified and separately costing those items required to reproduce the item under consideration.

Provincial and federal taxes were applied to those foods and beverages that are not classified as “basic groceries”, such as carbonated beverages, potato chips, granola products, and many sweetened baked goods (Canada Revenue Agency, 2017a; Province of Manitoba, 2014). Once prices and supply volumes were obtained for both diets, the author proceeded to calculate the cost per gram for all foods and beverages, and then tabulated the cost of each diet by multiplying these values by the quantity of each item consumed.

B.3 RESULTS

As a final step, I apply the results of the costing exercise to predict the financial costs associated with extreme AHEI values. Since both the healthy and unhealthy diets were both constructed by applying the assumption of negligible alcohol consumption, the design of the scoring mechanism presented in Chiuve et al. (2012) suggests that for the purposes of this exercise, the maximum and minimum possible AHEI scores are 102.5 and 2.5, respectively. To calculate the weekly and annual costs associated with diets characterized by these AHEI scores, I apply a simple linear trend; the results of this process are presented in Table 8:

Table 34: Results of extrapolation from reference diets to extreme AHEI values

Age	Diet	Afro-Caribbean		Asian-Indian		Caucasian	
		Male	Female	Male	Female	Male	Female
25-44	**AHEI Score: 102.5 (extrapolated)**	**$4,355.39**	**$3,164.41**	**$4,164.50**	**$2,987.79**	**$4,377.57**	**$3,161.73**
	Diet A	$4,702.85	$3,627.72	$4,491.31	$3,464.92	$4,727.46	$3,624.99
	Diet B	$5,763.03	$4,582.68	$5,495.93	$4,373.82	$5,794.10	$4,579.17
	AHEI Score: 2.5 (extrapolated)	**$6,545.94**	**$5,123.37**	**$6,202.93**	**$4,896.62**	**$6,586.18**	**$5,119.45**

Table 34: Results of extrapolation from reference diets to extreme AHEI values							
Age	**Diet**	**Afro-Caribbean**		**Asian-Indian**		**Caucasian**	
		Male	**Female**	**Male**	**Female**	**Male**	**Female**
45-64	**AHEI Score: 102.5 (extrapolated)**	**$3,938.56**	**$2,779.81**	**$3,747.45**	**$2,594.10**	**$3,960.77**	**$2,776.67**
	Diet A	$4,282.50	$3,322.94	$4,070.97	$3,160.14	$4,307.11	$3,320.20
	Diet B	$5,338.42	$4,274.80	$5,071.32	$4,065.95	$5,369.49	$4,271.29
	AHEI Score: 2.5 (extrapolated)	**$6,061.50**	**$4,835.85**	**$5,723.48**	**$4,612.41**	**$6,101.14**	**$4,832.10**
65-94	**AHEI Score: 102.5 (extrapolated)**	**$3,476.27**	**$2,331.79**	**$3,274.70**	**$2,144.55**	**$3,498.51**	**$2,328.63**
	Diet A	$3,816.47	$2,985.03	$3,604.94	$2,822.23	$3,841.08	$2,982.29
	Diet B	$4,867.65	$3,933.46	$4,600.55	$3,724.60	$4,898.72	$3,929.95
	AHEI Score: 2.5 (extrapolated)	**$5,528.39**	**$4,524.08**	**$5,209.97**	**$4,300.98**	**$5,567.41**	**$4,520.33**
Source: Author's calculations, based upon sources cited in text							

APPENDIX C: PHARMACIST CONSULTATION

C.1 RATIONALE FOR THE SELECTED APPROACH

Establishing the cost of pharmacotherapy for individuals with T2DM is methodologically challenging, since there is not obviously a "typical" course of pharmacotherapy for T2DM (any more than there is a "typical" T2DM patient), since patients' needs can evolve in many ways as their condition progresses, and since many also have access to some combination of private and public insurance coverage.

The author's objective for the consultation was to compile three "profiles" reflecting the utilization of medications and other supplies for T2DM patients whose condition varied according to time elapsed since diagnosis and the degree of vigilance applied to its management. It is essential to acknowledge the figures are intended primarily to provide a sense of the magnitude of the expenditures involved.

C.2 METHODOLOGY

To prepare for the consultation, the author developed and distributed a research instrument (presented below) outlining the objectives of the study and the information being sought. Following the interview, the author prepared and submitted a summary of the results to the subject matter expert to ensure the results had been recorded and interpreted accurately, making revisions as appropriate.

Modelling Patient Decision-Making Among Manitobans in the Context of Type II Diabetes Mellitus (T2DM): Drug Utilization and Costing Exercise

Objective

The goal of this exercise is to identify and ultimately cost a "standard" course of pharmacotherapy for people with T2DM at various stages of progression. For simplicity, we define progression solely in terms of age, time (years) elapsed since diagnosis and the patient's management of their condition.

We fully acknowledge that there is no such thing as an "average" diabetes patient, and that the pharmacological treatment of T2DM and its associated complications varies widely depending on the specifics of the patient's condition and the professional judgment of his or her health care practitioners. However, for the purposes of this research we are hoping to develop a small number of profiles that offer a reasonably general representation of T2DM patients' utilization of medications and other supplies typically sold in pharmacies, such as diabetic test strips.

Questions

As just noted, we would like to ask you to draw upon your experience and expertise as a health are practitioner to characterize a "standard" course of pharmacotherapy for three types of people with T2DM, namely

- people who have been recently diagnosed with T2DM;
- people who have had T2DM for many (10-15) years, but have managed their condition well; and
- people who have had T2DM for many (10-15) years, but have managed their condition poorly.

For each scenario, please consider the following questions:

1) What classes of medications might such patients use (e.g., antihyperglycemics, insulins, angiotensin converting enzymes, angiotensin receptor blockers, lipid-lowering medications, anti-platelet, etc.)?
2) Which specific product (or products) are most commonly prescribed within class you listed?
3) For each of the products you identified, what is the most commonly prescribed range of dosages/strengths?

Besides medications, what other products would you expect such patients to purchase from the pharmacy (e.g., syringes, lancets, blood glucose test strips, testing monitors, etc.)? For single-use products such as syringes and test strips, what would you estimate to be the average monthly cost that patients would incur **if they did not have private insurance and had not yet reached their Pharmacare deductible.**

C.3 Summary of Results

Below we present the results of the pharmacist consultation. It should be noted costs under each scenario considered here include acquisition cost and dispensing fees. Moreover, I assume the expense associated with the testing monitor to be negligible, since the subject matter expert indicated these are often provided to patients for free with the purchase of testing strips.

The first scenario involves an individual who has recently been diagnosed with T2DM. It was expected that such an individual could successfully manage their blood sugar levels by adhering to the use of two common oral antiglycemic agents (OAAs), and that such an individual would test their blood sugar once a day:

Table 35: Typical course of pharmacotherapy for individual with newly diagnosed T2DM

Drug class	Brand name	Generic name	Typical daily dosage	Approximate cost	
				Monthly	Annual
Antihyperglycemic (biguanide)	Glucophage	Metformin	2 mg	$20.00	$240.00
Antihyperglycemic (sulfonylureas)	Diamicron	Gliclazide	120 mg	$25.00	$300.00
Diabetic test strips	N/A	N/A	1.10 test strips[1]	$27.95	$335.34
Lancets	N/A	N/A	1.10 lancets[1]	$3.95	$47.34
TOTAL				$76.89	$922.68

[1] I assume individuals with newly-diagnosed T2DM use approximately 400 test strips per year (Canadian Diabetes Association, 2016b; Manitoba Health, Seniors and Active Living, 2017c), and that one lancet is used for each test.

Source: Expert opinion

Under the assumptions provided, a newly diagnosed individual with T2DM would spend approximately $76.89 per month for their medication in the absence of private or public insurance coverage, or $922.68 per year.

The second scenario considers patients who have had T2DM for many years but carefully managed their condition through a combination of diet, physical activity, and/or past adherence to pharmacotherapy. It is assumed such patients can treating their condition with insulin by relying upon additional antihyperglycemic agents; however, given their increased risk for macrovascular complications, it is assumed that such patients would generally be prescribed antihypertensive and lipid-lowering medications, as well as an anti-platelet:

Table 36: Typical course of pharmacotherapy for individual with established (10-15 years), well-managed T2DM

Drug class	Brand name	Generic name	Typical daily dosage	Approximate cost	
				Monthly	Annual
Antihyperglycemic (biguanide)	Glucophage	Metformin	2 mg	$20.00	$240.00
Antihyperglycemic (sulfonylureas)	Diamicron	Gliclazide	120 mg	$25.00	$300.00
Antihyperglycemic (sodium/glucose cotransporter 2 inhibitor)	Forxiga	Dapagliflozin	10 mg	$100.00	$1,200.00
Antihyperglycemic (Dipeptidyl peptidase 4)	Januvia	Sitagliptin	100 mg	$110.00	$1,320.00
Antihypertensive (angiotensin	Altace	Ramipril	10 mg	$20.00	$240.00

Table 36: Typical course of pharmacotherapy for individual with established (10-15 years), well-managed T2DM					
Drug class	**Brand name**	**Generic name**	**Typical daily dosage**	**Approximate cost**	
				Monthly	**Annual**
converting enzyme inhibitor)					
Lipid-lowering (statin)	Crestor	Rosuvastatin	20 mg	$24.00	$288.00
Anti-platelet	Aspirin	Acetylsalicylic acid	81 mg	$1.67	$20.00
Diabetic test strips	N/A	N/A	1.10 test strips[1]	$27.95	$335.34
Lancets	N/A	N/A	1.10 lancets[1]	$3.95	$47.34
TOTAL				$332.56	$3,990.68

[1] I assume individuals with newly-diagnosed T2DM use approximately 400 test strips per year (Canadian Diabetes Association, 2016b; Manitoba Health, Seniors and Active Living, 2017c), and that one lancet is used for each test.

Source: Expert opinion

As shown, under the assumptions provided, a patient who has had T2DM for many years but managed their condition appropriately would spend approximately $332.56 per month for their medication in the absence of private or public insurance coverage, or $3,990.68 per year, representing more than a three-fold increase in expenditures over the first scenario.

The final scenario considers drug utilization among patients who have had T2DM for many years but have failed to modify their lifestyle and/or to adhere to prescribed medications at earlier stages of disease progression. It is assumed many such patients will be required to manage their condition by using a combination of long-acting and rapid-acting insulins, necessitating more frequent monitoring of blood sugar levels. I further assume the patient has begun to experience microvascular and macrovascular complications, and is being treated accordingly:

Table 37: Typical course of pharmacotherapy for individual with established (~10 years), poorly managed T2DM					
Drug class	**Brand name**	**Generic name**	**Typical daily dosage**	**Approximate cost**	
				Monthly	**Annual**
Antihyperglycemic (biguanide)	Glucophage	Metformin	2 mg	$20.00	$240.00
Antihyperglycemic (sulfonylureas)	Diamicron	Gliclazide	120 mg	$25.00	$300.00
Insulin (long acting)	Novolin-N	Insulin	75 international units[2]	$90.00	$1,080.00
Insulin (rapid-acting)	Novolin-H	Insulin	75 international units[2]	$112.50	$1,350.00
Antihypertensive (angiotensin converting enzyme inhibitor)	Altace	Ramipril	10 mg	$20.00	$240.00
Lipid-lowering (statin)	Crestor	Rosuvastatin	20 mg	$24.00	$288.00
Anti-platelet	Aspirin	Acetylsalicylic acid	81 mg	$1.67	$20.00
Anti-platelet	Plavix	Clopidogrel	75 mg[4]	$12.00	$144.00
Neuropathic	Neurontin	Gabapentin	1,350 mg[5]	$68.00	$816.00
Diabetic test strips	N/A	N/A	2 test strips[1]	$51.00	$612.00
Syringes	N/A	N/A	3 syringes[3]	$45.00	$540.00
Lancets	N/A	N/A	2 lancets[1]	$7.20	$86.40
TOTAL				$476.37	$5,716.40

1 I assume these patients use about 2 test strips per day, which aligns with observed patterns of utilization in the Province of Manitoba for individuals who use insulin and OAAs concurrently (Patented Medicine Prices Review Board, 2013, p. 13). This falls well-within the level of Pharmacare Program coverage extended to individuals who use insulin (Canadian Diabetes Association, 2016b; Manitoba Health, Seniors and Active Living, 2017c). I further assume that one lancet is used each time the patient tests his or her blood sugar.

2 Insulin utilization can vary widely across patients; however, 50-100 international units constitutes a reasonably representative daily range. The mean of these two values is used for the costing exercise.

3 The patient injects insulin three times daily; a clean syringe is required for each injection.

Table 37: Typical course of pharmacotherapy for individual with established (~10 years), poorly managed T2DM					
Drug class	**Brand name**	**Generic name**	**Typical daily dosage**	**Approximate cost**	
				Monthly	**Annual**
[4] The patient has been prescribed another anti-platelet after suffering macrovascular complications. [5] The patient has begun to experience peripheral diabetic neuropathy and has been prescribed gabapentin for the management of neuropathic pain. 900-3600 mg constitutes a reasonably representative daily dosage range. The mean of these two values is used for the costing exercise. **Source:** Expert opinion; test strip utilization derived from the Patented Medicine Prices Review Board (2013); price for Plavix derived from Magnasson et al. (2018)					

Under the assumptions provided, patients would spend approximately $476.37 per month for their medication in the absence of private or public insurance coverage, or $5,716.40 per year, representing more than a 43.2% increase in expenditures over the second scenario and more than a five-fold increase in expenditures over the first scenario.

APPENDIX D: PREPARING THE UKPDS INPUT SHEETS

The template referenced in Section 3.6.2 is a macro-enabled Excel workbook (.xlsm) is designed to facilitate use of the decision model by those who have licensed the UKPDS-OM2. The macro embedded in the template is accessible through a button located on the user ribbon at the top of the screen:

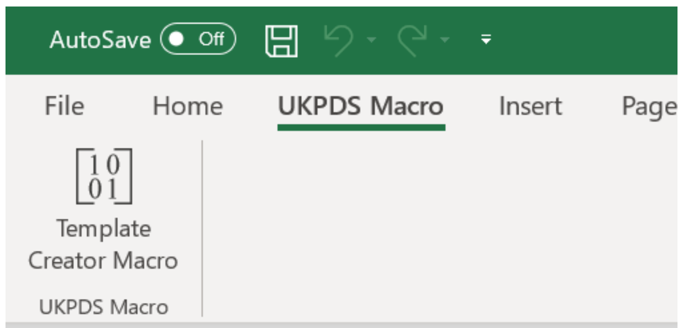

Figure 13: Accessing the Template Creator Macro in Excel

The macro applies the following settings to each simulation:

- *Loops and bootstraps.* The UKPDS-OM2 was designed to account for both first- and second-order uncertainty. Monte Carlo or first-order uncertainty, which is also known as variability, refers to variability in outcomes among patients with the same observed characteristics (Drummond et al., 2015, pp. 389–390; Hayes et al., 2013a, p. 1928). By contrast, parameter or second-order uncertainty refers to the estimated coefficients of the UKPDS-OM2 risk equations—the values of which cannot be known with certainty but only within a certain parameter distribution (Hayes et al., 2013a, p. 1928).

- First-order uncertainty was addressed by executing 100,000 loops for each simulation run, well in excess of the minimum recommended to obtain stable patient level estimates (University of Oxford Diabetes Trials Unit & Health Economics Research Centre, 2015, p. 20).

- For the purposes of this analysis it was deemed satisfactory to accept the values of the estimated coefficients underpinning the UKPDS-OM2 as given, since the decision-model itself is currently equipped only to use point estimates of the transition probabilities and HRQoL values generated through the UKPDS-OM2 simulations. As such, the number of bootstraps for each simulation run is set equal to zero.

- *Years simulated.* Each simulation run is set to track patient outcomes over a 70-year horizon, which is the maximum the model is currently equipped to accommodate (University of Oxford Diabetes Trials Unit & Health Economics Research Centre, 2015, p. 22).

- *Number of processes to use.* The simulations were carried out on an ASUS Notebook with an Intel® Core™ i7-8550U processor with four cores and eight logical processes; calculations were executed using four of the eight processes to expedite their completion.

- *Quality adjusted life expectancy/life expectancy and total costs discount rate.* The UKPDS-OM2 allows the user to specify separate discount rates for quality-adjusted life expectancy/life expectancy and total costs. For the purposes of this analysis, both rates were set equal to zero for the entire simulation horizon; applying discounting during the simulations would not only be redundant (i.e., since time preferences are incorporated into the design of the decision model) but would also result in inaccurate HRQoL figures.

- *Therapy and complication costs.* One powerful feature of the UKPDS-OM2 is the ability to track the cost of treating T2DM and its complications. This feature is not directly pertinent to the decision model, since individual decision-making is assumed to be driven solely by the costs patients bear themselves, which is assumed limited to a proportion of the costs of pharmacotherapy (see Section 3.5.1).

- *HRQoL.* The UKPDS-OM2 is also designed to track the quality-of-life impacts associated with T2DM and its complications. The default values incorporated into the model are drawn from an analysis of questionnaires administered during the UKPDS by Alva et al. (2014), as well as from a meta-analysis conducted by Lung, Hayes, Hayen, Farmer, and Clarke (2011). As with therapy and complication costs, the model enables the user to specify their own HRQoL values; for the purposes of this research, however, it was deemed sufficient to rely upon the defaults provided.

APPENDIX E: MANITOBA TYPE 2 DIABETES MELLITUS INDIVIDUAL OPTIMIZATION MODEL—USER GUIDE

The intent of this document is to furnish prospective users of the Manitoba Type 2 Diabetes Mellitus (T2DM) Individual Optimization Model (hereafter, the "decision model") with the background information necessary to set up, solve, and apply a dynamic stochastic optimization problem concerning individual health-related decision-making among those at risk for T2DM in the Province of Manitoba. The document provides step-by-step instructions on how to successfully deploy the model, prepare and solve the optimization problem, implement sensitivity analyses around key parameters, and design and execute simple microsimulation exercises using model-generated results.

Prior to, or concurrent with the review of the document, the reader is strongly encouraged to consult the thesis motivating and supplying both the conceptual foundation for the decision model and a complete list of references for all data sources used to select parameter values. It furthermore explains how to interpret model-generated outputs, including those produced by the supplementary microsimulation module. The thesis is freely available to the public at the following location on MSpace, an online repository for intellectual output created by researchers associated with the University of Manitoba (2018):

<LINK TO ZIP FILE HERE>

Prospective users may also benefit from consulting an online demonstration developed by the author, which covers roughly the same subject matter presented below. The demonstration is accessible at: https://youtu.be/1u50_bkacx0.

E.1 OVERVIEW

The decision model consists of an integrated collection of programs developed by the author in R, MATLAB and Excel Visual Basic for Applications. The model comes packaged with or is programmed to acquire all materials required to replicate the findings presented in the thesis, excepting those listed below. It processes and compiles these materials into a format appropriate for integration into the dynamic optimization problem, which is then solved by applying the backward induction algorithm. The steps involved in implementing the decision model are depicted in Figure 14 below.

The model outputs the decision-maker's optimal policy and value function, which may themselves be of interest but can also be used to drive microsimulation exercises that illustrate how the projected prevalence and incidence of T2DM in Manitoba, and direct and/or indirect losses attributable to the condition, may vary in populations with prespecified characteristics in different user-defined scenarios.

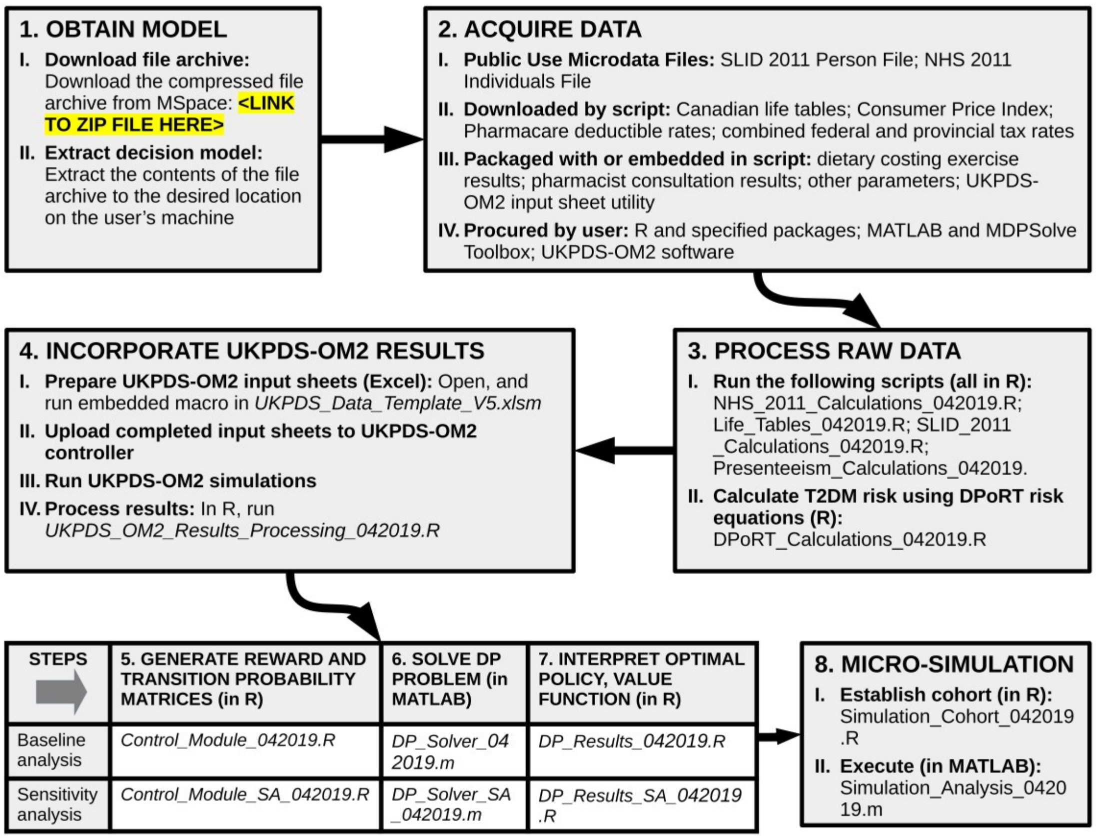

Figure 14: "Cheat sheet" for the implementation and application of the decision model

The remainder of this document walks the user through the implementation and solution of the decision model, with reference to the steps depicted in Figure 14.

E.2 STEP 1—OBTAINING THE MODEL

Once downloaded from MSpace, the contents of the file archive can be extracted to any location on the user's machine (the reference to the C:\ directory in Table 38 below is purely illustrative). The user should not attempt to manipulate the model's file structure, as this may detrimentally impact its operation; however, they should be familiar with this structure to facilitate access to model outputs and, where necessary, to permit troubleshooting:

Table 38: Decision model file structure

Directory	Description
C:\...\Diabetes_Model_042019	This is the base directory, containing the R and MATLAB scripts required to assign parameter values for and solve the decision model, and to interpret and apply the results.
C:\...\Diabetes_Model_042019\ MATLAB	This folder contains the reward and transition probability matrices driving the solution of the DP problem, as well as the resulting optimal policies and value functions. It also contains the results of the microsimulation exercise described in Section 5 in Chapter 4 of the thesis.
C:\...\Diabetes_Model_042019\ R_Objects	This folder contains intermediate calculations performed using a combination of data from a variety of sources, the results of which will be utilized in downstream calculations.
C:\...\Diabetes_Model_042019\ Raw_Data	This folder holds data sources feeding into the process of assigning values or ranges to model parameters. As the directory name suggests, the contents generally should not be renamed or manipulated outside the program itself.
C:\...\Diabetes_Model_042019\ UKPDS_OM2	This folder holds all the materials associated with the UKPDS-OM2, including the utility developed to facilitate preparation of the input sheets, the input sheet template, and the UKPDS-OM2 simulation outputs. It is recommended that a shortcut to the UKPDS-OM2 controller also be stored here, although this is not required.

E.3 STEP 2—ACQUIRING THE DATA

Two types of inputs are required to operate the decision model. First, as implied by Figure 14, the user must possess a working copy of R, RStudio, MATLAB and Excel.[43] They must also acquire and install the R packages listed in Table 39, which extend the functionality of the R software environment; the MDPSolve Toolbox, freely available from a website maintained by Paul Fackler (2014), which includes a function that implements the backward induction algorithm in MATLAB; and the United Kingdom Prospective Diabetes Study Outcomes Model v2 (UKPDS-OM2), which is licensed free of charge to academic organizations by the University of Oxford (Diabetes Trials Unit, 2018).

Table 39: R packages employed in the decision model		
❖ CANSIM2R (1.14.1)	❖ httr (1.4.0)	❖ readxl (1.3.1)
❖ data.table (1.12.2)	❖ jsonlite (1.6)	❖ reshape2 (1.4.3)
❖ dplyr (0.8.0.1)	❖ knitr (1.22)	❖ rvest (0.3.3)
❖ formattable (0.2.0.1)	❖ lubridate (1.7.4)	❖ stringr (1.4.0)
❖ ggplot2 (3.1.1)	❖ magrittr (1.5)	❖ tibble (2.1.1)
❖ gsubfn (0.7)	❖ openxlsx (4.1.0)	❖ tidyr (0.8.3)
❖ here (0.1)	❖ pdftools (2.2)	❖ xlsx (0.6.1)
❖ htmlTable (1.13.1)	❖ purrr (0.3.2)	❖ xtable (1.8-3)

43 The model has been thoroughly tested and functions as intended using R version 3.5.3 (via version 1.2.1335 of the RStudio integrated development environment for R), MATLAB 2018a, and Excel 2016. Versions of all R packages I employed in running the model are listed in Table 39. As with any piece of software, compatibility with programs other than those listed there (e.g., substituting Octave for MATLAB) or different versions of these programs is difficult to predict in advance.

Important: Before proceeding, the user must set the default working directory in RStudio to the base directory defined in Table 38 above, as this enables the model to identify the location from which scripts are being run. This can be accomplished by accessing the Global Options interface through the Tools menu and selecting the appropriate directory under "R Sessions" in General options.

Second, the decision model requires data from several sources to support the assignment of parameter values. This information falls into the categories listed in Table 40. The model either includes, or is programmed to automatically acquire all necessary inputs except the 2011 National Household Survey (NHS) and 2011 Survey of Labour and Income Dynamics (SLID) Use Microdata Files (PUMFs), which the user must obtain and store in the location specified below:

Table 40: Overview of model inputs

Input type	Description	User considerations
Microdata files	2011 NHS and 2011 SLID PUMFs are used to calculate household income and to derive employment state transition probabilities.	The PUMFs are freely available to Canadian post-secondary educational institutions participating in the Data Liberation Initiative. Once acquired, these files should be stored in *C:\...\ Diabetes_Model_042019\Raw_Data*. The files must not be renamed, nor should they be manipulated in any way.
Information downloaded by the model	This includes life tables for Canada and the Consumer Price Index available from the Statistics Canada website (Statistics Canada, 2018a), and combined federal and provincial	This information is collected automatically by the program through the application of web-scraping techniques. The user must therefore possess an active Internet connection when the associated scripts (*NHS_2011_Calculations _042019.R* and *Life_Tables_042019.R*) are run for the model to function as intended.

Table 40: Overview of model inputs		
Input type	**Description**	**User considerations**
	personal income tax rates for 2018 (EY, 2018).	
Information packaged with the model	A few data sources are packaged with the model on MSpace. These include summary tables from the pharmacist consultation and the dietary costing exercise.	This information is stored in *C:\...\Diabetes_Model_042019\Raw_Data*. Users not well-acquainted with the model or with relatively little programming experience are advised to refrain from renaming or otherwise manipulating these files.
Other inputs	The values of all remaining parameters are embedded directly in the model.	Where said values are derived from external sources, the latter are typically referenced explicitly in Chapter 4 as well as in the accompanying script. Where they are assumed, this, too, is generally indicated in the script.

E.4 Steps 3-4—Processing the data and incorporating UKPDS-OM2 simulation results

The user now processes the inputs listed above to construct the transition probability and reward matrices, two central components of the decision problem. One achieves this by running several scripts in the order indicated in Table 41:

Table 41: Overview of data processing steps		
File name	**Program**	**Function and prerequisites, if applicable**
NHS_2011_Calculations_042019.R	R	Uses data from the NHS 2011 PUMF (Statistics Canada, 2014) and information regarding federal and provincial tax rates (EY, 2018) to tabulate household employment and retirement income. ***No prerequisites.***
Life_Tables_042019.R	R	Uses data from the 2014-16 life tables for Manitoba (Statistics Canada, 2018a), to calculate the likelihood of mortality by age and gender for healthy individuals. Also calculates life expectancy at birth (used in calculating the number of years of which people will

Table 41: Overview of data processing steps		
		continue drawing upon personal savings in retirement). ***No prerequisites.***
SLID_2011_Calculations_042019.R	R	Drawing upon the 2011 SLID PUMF (Statistics Canada, 2014), calculates the probability of annual employment state transitions for individuals of varying age, gender, and level of educational attainment. ***No prerequisites.***
Presenteeism_Calculations_042019.R	R	Drawing upon results presented in Lavigne et al. (2003), calculates monthly productivity losses attributable to T2DM by age, gender, ethnicity, and level of educational attainment. ***No prerequisites.***
DPoRT_Calculations_042019.R	R	Drawing upon risk equations published by Rosella et al. (2014), calculates the probability of transitioning from healthy to T2DM for individuals varying by age, gender, ethnicity, level of educational attainment, and adherence to LTPA and healthy eating habits. ***User must first have executed the script entitled NHS_2011_Calculations_042019.R.***
UKPDS_Data_Template_V5.xlsm	Visual Basic for Applications	Generates input sheets for use by the UKPDS-OM2 model. ***User must first have executed the script entitled DPoRT_Calculations_042019.R.***
UKPDS-OM2 controller	Custom-built application	Calculates the likelihood of mortality, HRQoL, and workplace absenteeism. ***User must first have run the macro embedded in UKPDS_Data_Template_V5.xlsm, which is accessible through a button located on the user ribbon at the top of the screen under the "UKPDS Macro" tab.***
UKPDS_OM2_Results_Processing_042019.R	R	Processes the results of the simulations implemented by the UKPDS-OM2 to facilitate integration into the decision model. ***User must first have carried out these simulations through the UKPDS-OM2 controller.***

The scripts listed in Table 41 need only be executed once, as opposed to later scripts, which the user may wish to run several times (e.g., for the purposes of conducting sensitivity analyses). To supplement the table, Figure 15 demonstrates precisely how the model processes and combines raw data from a wide range of sources to construct the inputs needed to set up the decision problem:

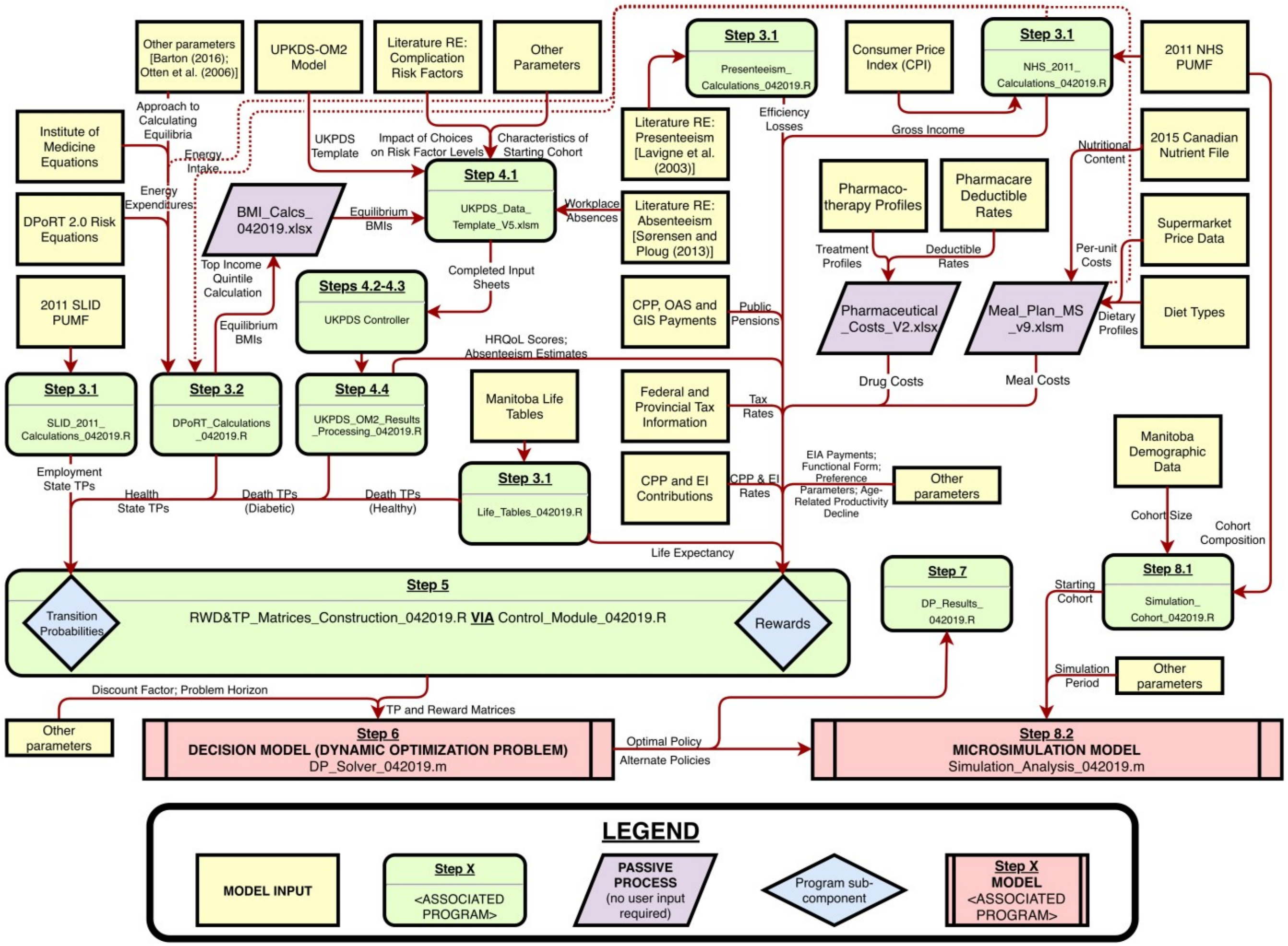

Figure 15: Flowchart illustrating the compilation of model inputs from raw data

It should be noted that whereas the UKPDS-OM2 data template and the R script for processing UKPDS-OM2 simulation results were both developed through this research, and are briefly discussed in Section 3.6.2 in Chapter 3 of the thesis as well as in Appendix D. However, the UKPDS-OM2 itself was created by the Diabetes Trials Unit and Health Economics Research Centre at the University of Oxford. I therefore refer the reader to user documentation prepared by those institutions for additional information regarding its use (University of Oxford Diabetes Trials Unit & Health Economics Research Centre, 2015).

E.5 STEP 5—GENERATING THE REWARD AND TRANSITION PROBABILITY MATRICES

The preceding steps culminate in the construction of the transition probability and reward matrices. Generation of these critical inputs for the baseline and sensitivity analyses is undertaken by executing *Control_Module_042019.R* and *Control_Module_SA_042019.R*, respectively, both of which are stored in the base directory, and which function by passing parameters to *RWD&TP_Matrices_Construction_042019.R* and extracting the results:

- Results for the baseline analysis are stored in the subfolders "RWD_Matrix_Components" and "TP_Matrix_Components" in C:\...\Diabetes_Model_042019\MATLAB\Baseline_Results\MATLAB_Output.

❖ Results for the sensitivity analysis are stored in similarly labelled subfolders in C:\...\Diabetes_Model_042019\MATLAB\Sensitivity_Analysis*\MATLAB_Output; in this case, however, the model saves separate sets of results for each parameter varied in the analysis (denoted by the asterisk).

For the baseline analysis, the model will by default produce transition probability and reward matrices for decision-makers with all 24 combinations of gender, ethnicity (i.e., Afro-Caribbean, Asian-Indian and Caucasian), and education (i.e., no certificate, diploma or degree, high school diploma or equivalent, post-secondary certificate or diploma below bachelor level, or university certificate, diploma, or degree at bachelor level or above) incorporated into the model.

For the sensitivity analysis the user must specify the characteristics of the decision-maker serving as the basis for the analysis.

E.6 STEPS 6-7—SOLVING THE DYNAMIC OPTIMIZATION PROBLEM AND INTERPRETING THE RESULTS

The user can now solve the decision model in MATLAB by initializing *DP_Solver_042019.m* or *DP_Solver_SA_042019.m* from the base directory (C:\...\Diabetes_Model_042019), which implement the baseline and sensitivity analyses, respectively. Both scripts employ backward induction techniques using the *mdpsolve* function packaged with the MDPSolve Toolbox. To function properly, the function requires the user to supply suitable reward and transition probability matrices (produced in the previous step) and specify the decision-maker's discount factor how far into the future the optimization problem extends (specified in the scripts themselves).

The decision model generates optimal policies and value functions for each combination of gender, ethnicity and level of education. These are stored as DAT files in separate folders (i.e., one for each person "type") within the following sub-directories:

- *Baseline analysis:* C:\...\Diabetes_Model_042019\MATLAB\Baseline_Results\MATLAB_Output.

- *Sensitivity analysis (the asterisk is a placeholder for sub-folders for each parameter varied in the analysis):* C:\...\Diabetes_Model_042019\MATLAB\Sensitivity_Analysis*\ MATLAB_Output.

The model also includes two R scripts in the base directory which support interpretation of the solution to the dynamic optimization problem and replicate the summary tables presented in Section 3.2 in Chapter 4 of the thesis, as well as in Appendix F and Appendix G. *DP_Results_042019.R* generates results for the baseline analysis, while *DP_Results_SA_042019.R* and produces optimal policies and value functions for the sensitivity analysis.

Upon executing the backward induction algorithm, MATLAB will commonly warn the user that some rows of the transition probability matrix do not sum to 0. This appears attributable to a loss of precision occurring when matrix components are written into Excel from R. Although there is no straightforward remedy, the figures in question are extremely small (on the order of 10^{-9} or less) and are expected to have little or no impact on the model results.

In passing, I note that generating the transition probability and reward matrices and solving the dynamic optimization problem are computationally intensive operations that rely upon the application of a range of memory and performance management techniques, including the following:[44]

- *Preallocating memory to arrays.* Preallocation of memory to an array is often recommended as a means of improving performance, because MATLAB requires additional time to incrementally increase the size of a data structure

[44] Another option considered for memory and performance management included using single-precision floating point numbers in calculations, which require only half as much memory as double-precision floating point numbers). This was ultimately determined not to be viable, because sparse matrices (which are central to the construction of the transition probability matrices) work only with double or logical data (MathWorks, Inc., 2017b).

(MathWorks, Inc., 2017a). This was accomplished by simply pre-specifying the size of each data structure and assigning zero values to each entry; subsequent calculations then replace these values as required.

- *Employing sparse arrays.* Sparse arrays are data structures that are mostly empty, storing only non-zero elements and their row indices (MathWorks, Inc., 2017b). When data density is sufficiently low,[45] they can substantially reduce the amount of memory required for data storage, and may also improve performance (Altman, 2014, pp. 137–138). Sparse arrays are extremely useful within the context of the individual decision model, because the density of the transition probability matrix is approximately 1.31 x 10^{-5}.[46]

- *Applying matrix manipulation techniques.* The amount of memory required to store a sparse matrix depends upon both the number of non-zero entries and the number of matrix columns.[47] For example, a sparse matrix consisting of a

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45 In a full matrix, 8 bytes is required to hold a single double-precision floating point number in memory; thus, an *m*x*n* matrix requires 8x*m*x*n* bytes of memory. By contrast, the minimum data storage requirement on a 64-bit system for a double *m*x*n* sparse matrix with *nnz* non-zero elements is as follows: $bytes = max(nnz, 1) \times 16 + (n + 1) \times 8$, where *n* is the number of matrix columns (MathWorks, Inc., 2014). This demonstrates that sparse matrices require more memory to store each data entry, which is why they are less efficient than full matrices when data density is high.

46 The transition probability matrix is 228,357 x 228,357; however, there are only 685,065 possible transitions.

47 Refer to footnote 45 for a discussion of memory storage requirements for sparse arrays. Requirements for N-dimensional sparse arrays depend on the number of non-zero entries and the length of the last dimension of the array.

single row and one trillion columns would require a minimum of approximately 8,000 GB of memory, easily exceeding the working memory of the author's computer, while a sparse matrix consisting of one trillion rows and a single column would require a minimum of only 32 bytes. This suggests that it is preferable from a memory management standpoint to store sparse matrices in such a way that the last dimension is the shortest, recognizing that it is always possible to transpose or rearrange the matrix.

- *Vectorization (implicit parallelization).* While it is often convenient to undertake repetitive operations by applying for-loops, this is often very time-consuming and can be prone to error. In many instances, it is possible to achieve dramatic improvements in performance through vectorization, which applies a specific operation to an entire array simultaneously, taking advantage of opportunities to carry out operations in parallel rather than sequentially (Altman, 2014, p. 223; MathWorks, Inc., 2018).

E.7 STEP 8—UNDERTAKING MICROSIMULATIONS

Before continuing, the user must solve the dynamic optimization problem using baseline parameter values by executing *DP_Solver_042019.m* in MATLAB from the base directory (i.e., C:\...\Diabetes_Model_042019). This generates the optimal transition matrices that drive the simulation model. In addition, they must define the characteristics of the patient cohort whose health and economic transitions they wish to study. The user can replicate the results presented in this thesis by executing *Simulation_Cohort_042019.R* in R (also located in the base directory).

With this complete, the user can conduct patient-level microsimulations in MATLAB by running *Simulation_Analysis_042019.m*. The figures presented in Section 5.3 in Chapter 4 of the thesis are stored in C:\...\Diabetes_Model_042019\MATLAB\Simulation_Results\Figures, while detailed data tables containing the simulation results can be found in C:\...\Diabetes_Model_042019\MATLAB\Simulation_Results\Tables.

NOTE: To promote reproducibility of results, the microsimulation program seeds MATLAB's random number generator using the same nonnegative integer seed for each run (i.e., '1234' with the Mersenne Twister generator algorithm). However, the user can easily disable this feature by modifying the value of the variable **Thesis_Results**, which, unless set equal to one, initializes the microsimulation using whatever the random seed may be on the user's machine at that time.

APPENDIX F: BASELINE ANALYSIS DATA TABLES

Table 42: Characteristics of the optimal policy for individuals with varying personal characteristics, by age, and health and employment status

Value	Employment Status	Healthy			Newly Diagnosed				T2DM, Poor Adherence				T2DM, Good Adherence			
		LTPA	Diet	LMP	LTPA	Diet	Meds	LMP	LTPA	Diet	Meds	LMP	LTPA	Diet	Meds	LMP
Male; Caucasian; no certificate, diploma or degree																
25	E	DA	A	FT												
25	U	DA	A	FT												
35	E	DA	A	FT	DA	A	A	FT								
35	U	DA	A	FT	DA	A	A	FT								
45	E	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
45	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
55	E	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
55	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
65	E	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
65	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
75	E	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
75	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
85	E	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
85	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
Male; Caucasian; high school diploma or equivalent																
25	E	DA	DA	FT												
25	U	DA	A	FT												
35	E	DA	A	FT	DA	A	A	FT								
35	U	DA	A	FT	DA	A	A	FT								
45	E	A	DA	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
45	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
55	E	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
55	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
65	E	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
65	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
75	E	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
75	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
85	E	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
85	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT

Table 42: Characteristics of the optimal policy for individuals with varying personal characteristics, by age, and health and employment status

Value	Employment Status	Healthy			Newly Diagnosed				T2DM, Poor Adherence				T2DM, Good Adherence			
		LTPA	Diet	LMP	LTPA	Diet	Meds	LMP	LTPA	Diet	Meds	LMP	LTPA	Diet	Meds	LMP
Male; Caucasian; post-secondary certificate or diploma below bachelor level																
25	E	DA	DA	FT												
25	U	DA	A	FT												
35	E	A	DA	FT	DA	A	A	FT								
35	U	DA	A	FT	DA	A	A	FT								
45	E	A	DA	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
45	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
55	E	A	DA	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
55	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
65	E	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
65	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
75	E	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
75	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
85	E	DA	A	RT	DA	A	DA	RT	DA	A	A	RT	DA	A	A	RT
85	U	DA	A	RT	DA	A	DA	RT	DA	A	A	RT	DA	A	A	RT
Male; Caucasian; university certificate, diploma, or degree at bachelor level or above																
25	E	DA	DA	FT												
25	U	DA	A	FT												
35	E	A	DA	FT	A	DA	A	FT								
35	U	DA	A	FT	DA	A	A	FT								
45	E	A	DA	FT	A	DA	A	FT	DA	A	A	FT	DA	A	A	FT
45	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
55	E	A	DA	FT	A	DA	A	FT	DA	A	A	FT	DA	A	A	FT
55	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
65	E	A	DA	FT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
65	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
75	E	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
75	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
85	E	DA	A	RT	DA	A	DA	RT	DA	A	A	RT	DA	A	A	RT
85	U	DA	A	RT	DA	A	DA	RT	DA	A	A	RT	DA	A	A	RT

Table 42: Characteristics of the optimal policy for individuals with varying personal characteristics, by age, and health and employment status

Value	Employment Status	Healthy			Newly Diagnosed				T2DM, Poor Adherence				T2DM, Good Adherence			
		LTPA	Diet	LMP	LTPA	Diet	Meds	LMP	LTPA	Diet	Meds	LMP	LTPA	Diet	Meds	LMP
Male; Afro-Caribbean; no certificate, diploma or degree																
25	E	DA	A	FT												
25	U	DA	A	FT												
35	E	DA	A	FT	DA	A	A	FT								
35	U	DA	A	FT	DA	A	A	FT								
45	E	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
45	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
55	E	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
55	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
65	E	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
65	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
75	E	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
75	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
85	E	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
85	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
Male; Afro-Caribbean; high school diploma or equivalent																
25	E	DA	DA	FT												
25	U	DA	A	FT												
35	E	DA	A	FT	DA	A	A	FT								
35	U	DA	A	FT	DA	A	A	FT								
45	E	A	DA	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
45	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
55	E	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
55	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
65	E	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
65	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
75	E	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
75	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
85	E	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
85	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT

Table 42: Characteristics of the optimal policy for individuals with varying personal characteristics, by age, and health and employment status

Value	Employment Status	Healthy			Newly Diagnosed				T2DM, Poor Adherence				T2DM, Good Adherence			
		LTPA	Diet	LMP	LTPA	Diet	Meds	LMP	LTPA	Diet	Meds	LMP	LTPA	Diet	Meds	LMP
Male; Afro-Caribbean; post-secondary certificate or diploma below bachelor level																
25	E	DA	DA	FT												
25	U	DA	A	FT												
35	E	A	DA	FT	DA	A	A	FT								
35	U	DA	A	FT	DA	A	A	FT								
45	E	A	DA	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
45	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
55	E	A	DA	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
55	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
65	E	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
65	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
75	E	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
75	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
85	E	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
85	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
Male; Afro-Caribbean; university certificate, diploma, or degree at bachelor level or above																
25	E	DA	DA	FT												
25	U	DA	A	FT												
35	E	A	DA	FT	A	DA	A	FT								
35	U	DA	A	FT	DA	A	A	FT								
45	E	A	DA	FT	A	DA	A	FT	DA	DA	DA	FT	A	DA	A	FT
45	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
55	E	A	DA	FT	A	DA	A	FT	DA	A	A	FT	DA	A	A	FT
55	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
65	E	A	DA	FT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
65	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
75	E	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
75	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
85	E	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
85	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT

Table 42: Characteristics of the optimal policy for individuals with varying personal characteristics, by age, and health and employment status

Value	Employment Status	Healthy			Newly Diagnosed				T2DM, Poor Adherence				T2DM, Good Adherence			
		LTPA	Diet	LMP	LTPA	Diet	Meds	LMP	LTPA	Diet	Meds	LMP	LTPA	Diet	Meds	LMP
Male; Asian-Indian; no certificate, diploma or degree																
25	E	DA	DA	FT												
25	U	DA	A	FT												
35	E	DA	A	FT	DA	A	A	FT								
35	U	DA	A	FT	DA	A	A	FT								
45	E	A	DA	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
45	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
55	E	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
55	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
65	E	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
65	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
75	E	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
75	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
85	E	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
85	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
Male; Asian-Indian; high school diploma or equivalent																
25	E	DA	DA	FT												
25	U	DA	A	FT												
35	E	A	DA	FT	DA	A	A	FT								
35	U	DA	A	FT	DA	A	A	FT								
45	E	A	DA	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
45	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
55	E	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
55	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
65	E	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
65	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
75	E	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
75	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
85	E	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
85	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT

Table 42: Characteristics of the optimal policy for individuals with varying personal characteristics, by age, and health and employment status																
Value	**Employment Status**	**Healthy**			**Newly Diagnosed**				**T2DM, Poor Adherence**				**T2DM, Good Adherence**			
		LTPA	**Diet**	**LMP**	**LTPA**	**Diet**	**Meds**	**LMP**	**LTPA**	**Diet**	**Meds**	**LMP**	**LTPA**	**Diet**	**Meds**	**LMP**
Male; Asian-Indian; post-secondary certificate or diploma below bachelor level																
25	E	DA	DA	FT												
25	U	DA	A	FT												
35	E	A	DA	FT	DA	A	A	FT								
35	U	DA	A	FT	DA	A	A	FT								
45	E	A	DA	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
45	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
55	E	A	DA	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
55	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
65	E	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
65	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
75	E	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
75	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
85	E	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
85	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
Male; Asian-Indian; university certificate, diploma, or degree at bachelor level or above																
25	E	DA	DA	FT												
25	U	DA	A	FT												
35	E	A	DA	FT	A	DA	A	FT								
35	U	DA	A	FT	DA	A	A	FT								
45	E	A	DA	FT	A	DA	A	FT	A	DA	A	FT	A	DA	A	FT
45	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
55	E	A	DA	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
55	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
65	E	A	DA	FT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
65	U	A	DA	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
75	E	A	DA	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
75	U	A	DA	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
85	E	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
85	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT

Table 42: Characteristics of the optimal policy for individuals with varying personal characteristics, by age, and health and employment status

Value	Employment Status	Healthy			Newly Diagnosed				T2DM, Poor Adherence				T2DM, Good Adherence			
		LTPA	Diet	LMP	LTPA	Diet	Meds	LMP	LTPA	Diet	Meds	LMP	LTPA	Diet	Meds	LMP
Female; Caucasian; no certificate, diploma or degree																
25	E	DA	A	FT												
25	U	DA	A	FT												
35	E	DA	A	FT	A	A	DA	FT								
35	U	DA	A	FT	DA	A	A	FT								
45	E	DA	A	FT	A	A	DA	FT	DA	A	A	FT	DA	A	A	FT
45	U	DA	A	FT	A	A	DA	FT	DA	A	A	FT	DA	A	A	FT
55	E	DA	A	FT	A	A	DA	FT	DA	A	A	FT	DA	A	A	FT
55	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
65	E	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
65	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
75	E	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
75	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
85	E	DA	A	RT	DA	A	DA	RT	DA	A	A	RT	DA	A	A	RT
85	U	DA	A	RT	DA	A	DA	RT	DA	A	A	RT	DA	A	A	RT
Female; Caucasian; high school diploma or equivalent																
25	E	DA	DA	FT												
25	U	DA	A	FT												
35	E	DA	A	FT	DA	A	A	FT								
35	U	DA	A	FT	DA	A	A	FT								
45	E	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
45	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
55	E	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
55	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
65	E	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
65	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
75	E	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
75	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
85	E	DA	A	RT	DA	A	DA	RT	DA	A	A	RT	DA	A	A	RT
85	U	DA	A	RT	DA	A	DA	RT	DA	A	A	RT	DA	A	A	RT

Table 42: Characteristics of the optimal policy for individuals with varying personal characteristics, by age, and health and employment status

Value	Employment Status	Healthy			Newly Diagnosed				T2DM, Poor Adherence				T2DM, Good Adherence			
		LTPA	Diet	LMP	LTPA	Diet	Meds	LMP	LTPA	Diet	Meds	LMP	LTPA	Diet	Meds	LMP
Female; Caucasian; post-secondary certificate or diploma below bachelor level																
25	E	DA	DA	FT												
25	U	DA	A	FT												
35	E	DA	A	FT	DA	A	DA	FT								
35	U	DA	A	FT	DA	A	A	FT								
45	E	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
45	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
55	E	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
55	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
65	E	DA	A	RT	DA	A	DA	RT	DA	A	A	RT	DA	A	A	RT
65	U	DA	A	RT	DA	A	DA	RT	DA	A	A	RT	DA	A	A	RT
75	E	DA	A	RT	DA	A	DA	RT	DA	A	A	RT	DA	A	A	RT
75	U	DA	A	RT	DA	A	DA	RT	DA	A	A	RT	DA	A	A	RT
85	E	DA	A	RT	DA	A	DA	RT	DA	A	A	RT	DA	A	A	RT
85	U	DA	A	RT	DA	A	DA	RT	DA	A	A	RT	DA	A	A	RT
Female; Caucasian; university certificate, diploma, or degree at bachelor level or above																
25	E	DA	DA	FT												
25	U	DA	A	FT												
35	E	A	DA	FT	A	DA	A	FT								
35	U	DA	A	FT	DA	A	A	FT								
45	E	A	DA	FT	A	DA	A	FT	DA	A	A	FT	A	DA	A	FT
45	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
55	E	A	DA	FT	A	DA	A	FT	DA	A	DA	FT	DA	A	A	FT
55	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
65	E	A	DA	FT	A	DA	A	FT	DA	A	A	FT	DA	A	A	FT
65	U	DA	A	RT	DA	A	DA	RT	DA	A	A	RT	DA	A	A	RT
75	E	DA	A	RT	DA	A	DA	RT	DA	A	A	RT	DA	A	A	RT
75	U	DA	A	RT	DA	A	DA	RT	DA	A	A	RT	DA	A	A	RT
85	E	DA	A	RT	DA	A	DA	RT	DA	A	A	RT	DA	A	A	RT
85	U	DA	A	RT	DA	A	DA	RT	DA	A	A	RT	DA	A	A	RT

Table 42: Characteristics of the optimal policy for individuals with varying personal characteristics, by age, and health and employment status

Value	Employment Status	Healthy			Newly Diagnosed				T2DM, Poor Adherence				T2DM, Good Adherence			
		LTPA	Diet	LMP	LTPA	Diet	Meds	LMP	LTPA	Diet	Meds	LMP	LTPA	Diet	Meds	LMP
Female; Afro-Caribbean; no certificate, diploma or degree																
25	E	DA	A	FT												
25	U	DA	A	FT												
35	E	DA	A	FT	DA	A	A	FT								
35	U	DA	A	FT	DA	A	A	FT								
45	E	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
45	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
55	E	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
55	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
65	E	DA	A	RT	A	A	DA	RT	DA	A	A	RT	DA	A	A	RT
65	U	DA	A	RT	A	A	DA	RT	DA	A	A	RT	DA	A	A	RT
75	E	DA	A	RT	A	A	DA	RT	DA	A	A	RT	DA	A	A	RT
75	U	DA	A	RT	A	A	DA	RT	DA	A	A	RT	DA	A	A	RT
85	E	DA	A	RT	A	A	DA	RT	DA	A	A	RT	DA	A	A	RT
85	U	DA	A	RT	A	A	DA	RT	DA	A	A	RT	DA	A	A	RT
Female; Afro-Caribbean; high school diploma or equivalent																
25	E	DA	DA	FT												
25	U	DA	A	FT												
35	E	DA	A	FT	DA	A	A	FT								
35	U	DA	A	FT	DA	A	A	FT								
45	E	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
45	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
55	E	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
55	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
65	E	DA	A	RT	A	A	DA	RT	DA	A	A	RT	DA	A	A	RT
65	U	DA	A	RT	A	A	DA	RT	DA	A	A	RT	DA	A	A	RT
75	E	DA	A	RT	A	A	DA	RT	DA	A	A	RT	DA	A	A	RT
75	U	DA	A	RT	A	A	DA	RT	DA	A	A	RT	DA	A	A	RT
85	E	DA	A	RT	A	A	DA	RT	DA	A	A	RT	DA	A	A	RT
85	U	DA	A	RT	A	A	DA	RT	DA	A	A	RT	DA	A	A	RT

Table 42: Characteristics of the optimal policy for individuals with varying personal characteristics, by age, and health and employment status																
Value	**Employment Status**	**Healthy**			**Newly Diagnosed**				**T2DM, Poor Adherence**				**T2DM, Good Adherence**			
		LTPA	**Diet**	**LMP**	**LTPA**	**Diet**	**Meds**	**LMP**	**LTPA**	**Diet**	**Meds**	**LMP**	**LTPA**	**Diet**	**Meds**	**LMP**
Female; Afro-Caribbean; post-secondary certificate or diploma below bachelor level																
25	E	DA	DA	FT												
25	U	DA	A	FT												
35	E	DA	A	FT	DA	A	A	FT								
35	U	DA	A	FT	DA	A	A	FT								
45	E	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
45	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
55	E	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
55	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
65	E	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
65	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
75	E	DA	A	RT	A	A	DA	RT	DA	A	A	RT	DA	A	A	RT
75	U	DA	A	RT	A	A	DA	RT	DA	A	A	RT	DA	A	A	RT
85	E	DA	A	RT	A	A	DA	RT	DA	A	A	RT	DA	A	A	RT
85	U	DA	A	RT	A	A	DA	RT	DA	A	A	RT	DA	A	A	RT
Female; Afro-Caribbean; university certificate, diploma, or degree at bachelor level or above																
25	E	DA	DA	FT												
25	U	DA	A	FT												
35	E	A	DA	FT	A	DA	A	FT								
35	U	DA	A	FT	DA	A	A	FT								
45	E	A	DA	FT	A	DA	A	FT	A	DA	DA	FT	A	DA	A	FT
45	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
55	E	A	DA	FT	A	DA	A	FT	A	DA	DA	FT	DA	A	A	FT
55	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
65	E	A	DA	FT	A	DA	A	FT	DA	A	A	RT	DA	A	A	FT
65	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
75	E	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
75	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
85	E	DA	A	RT	A	A	DA	RT	DA	A	A	RT	DA	A	A	RT
85	U	DA	A	RT	A	A	DA	RT	DA	A	A	RT	DA	A	A	RT

Table 42: Characteristics of the optimal policy for individuals with varying personal characteristics, by age, and health and employment status

Value	Employment Status	Healthy			Newly Diagnosed				T2DM, Poor Adherence				T2DM, Good Adherence			
		LTPA	Diet	LMP	LTPA	Diet	Meds	LMP	LTPA	Diet	Meds	LMP	LTPA	Diet	Meds	LMP
Female; Asian-Indian; no certificate, diploma or degree																
25	E	DA	A	FT												
25	U	DA	A	FT												
35	E	DA	A	FT	DA	A	A	FT								
35	U	DA	A	FT	DA	A	A	FT								
45	E	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
45	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
55	E	DA	A	FT	A	A	DA	FT	DA	A	A	FT	DA	A	A	FT
55	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
65	E	DA	A	RT	A	A	DA	RT	DA	A	A	RT	DA	A	A	RT
65	U	DA	A	RT	A	A	DA	RT	DA	A	A	RT	DA	A	A	RT
75	E	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
75	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
85	E	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	A	RT
85	U	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	A	RT
Female; Asian-Indian; high school diploma or equivalent																
25	E	DA	DA	FT												
25	U	DA	A	FT												
35	E	DA	A	FT	DA	A	A	FT								
35	U	DA	A	FT	DA	A	A	FT								
45	E	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
45	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
55	E	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
55	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
65	E	DA	A	RT	A	A	DA	RT	DA	A	A	RT	DA	A	A	RT
65	U	DA	A	RT	A	A	DA	RT	DA	A	A	RT	DA	A	A	RT
75	E	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
75	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
85	E	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	A	RT
85	U	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	A	RT

Table 42: Characteristics of the optimal policy for individuals with varying personal characteristics, by age, and health and employment status

Value	Employment Status	Healthy			Newly Diagnosed				T2DM, Poor Adherence				T2DM, Good Adherence			
		LTPA	Diet	LMP	LTPA	Diet	Meds	LMP	LTPA	Diet	Meds	LMP	LTPA	Diet	Meds	LMP
Female; Asian-Indian; post-secondary certificate or diploma below bachelor level																
25	E	DA	DA	FT												
25	U	DA	A	FT												
35	E	DA	A	FT	DA	A	A	FT								
35	U	DA	A	FT	DA	A	A	FT								
45	E	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
45	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
55	E	DA	A	FT	DA	A	A	FT	DA	A	DA	FT	DA	A	A	FT
55	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
65	E	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
65	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
75	E	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
75	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
85	E	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	A	RT
85	U	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	A	RT
Female; Asian-Indian; university certificate, diploma, or degree at bachelor level or above																
25	E	DA	DA	A												
25	U	DA	A	A												
35	E	A	DA	A	A	DA	A	FT								
35	U	DA	A	A	DA	A	A	FT								
45	E	A	DA	A	A	DA	A	FT	A	DA	DA	FT	DA	A	A	FT
45	U	DA	A	A	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
55	E	A	DA	A	A	DA	A	FT	A	DA	DA	FT	A	DA	A	FT
55	U	DA	A	A	DA	A	A	FT	DA	A	DA	FT	DA	A	A	FT
65	E	A	DA	A	DA	A	A	FT	DA	A	A	RT	DA	A	A	FT
65	U	DA	A	A	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
75	E	DA	A	A	DA	A	A	RT	DA	A	DA	RT	DA	A	A	RT
75	U	DA	A	A	DA	A	A	RT	DA	A	DA	RT	DA	A	A	RT
85	E	DA	A	A	DA	A	DA	RT	DA	A	DA	RT	DA	A	A	RT
85	U	DA	A	A	DA	A	DA	RT	DA	A	DA	RT	DA	A	A	RT

Table 43: Estimates of the value function for individuals with varying personal characteristics, by age, and health and employment status					
Age	**Employment Status**	**Healthy**	**Newly Diagnosed (Year 0)**	**T2DM, Poor Adherence (Year 9)**	**T2DM, Good Adherence (Year 9)**
Male; Caucasian; no certificate, diploma or degree					
25	Employed	158,736	NA	NA	NA
25	Unemployed	152,803	NA	NA	NA
35	Employed	158,691	114,626	NA	NA
35	Unemployed	151,671	109,318	NA	NA
45	Employed	151,563	114,945	101,067	109,285
45	Unemployed	143,384	108,684	96,083	103,766
55	Employed	140,571	103,251	88,914	96,396
55	Unemployed	131,305	96,317	83,532	90,293
65	Employed	139,653	100,196	68,143	77,245
65	Unemployed	139,653	100,196	68,143	77,245
75	Employed	96,825	67,811	45,877	52,381
75	Unemployed	96,825	67,811	45,877	52,381
85	Employed	52,406	38,115	30,983	35,461
85	Unemployed	52,406	38,115	30,983	35,461
Male; Caucasian; high school diploma or equivalent					
25	Employed	171,823	NA	NA	NA
25	Unemployed	165,553	NA	NA	NA
35	Employed	171,959	124,518	NA	NA
35	Unemployed	164,171	118,525	NA	NA
45	Employed	159,979	121,226	106,568	115,207
45	Unemployed	152,090	115,145	101,700	109,852
55	Employed	149,160	109,628	94,218	102,179
55	Unemployed	140,080	102,729	88,850	96,132
65	Employed	147,198	105,788	71,975	81,575
65	Unemployed	147,198	105,788	71,975	81,575
75	Employed	100,551	70,658	47,897	54,665
75	Unemployed	100,551	70,658	47,897	54,665
85	Employed	52,925	38,511	31,262	35,781
85	Unemployed	52,925	38,511	31,262	35,781

Table 43: Estimates of the value function for individuals with varying personal characteristics, by age, and health and employment status					
Age	**Employment Status**	**Healthy**	**Newly Diagnosed (Year 0)**	**T2DM, Poor Adherence (Year 9)**	**T2DM, Good Adherence (Year 9)**
Male; Caucasian; post-secondary certificate or diploma below bachelor level					
25	Employed	187,744	NA	NA	NA
25	Unemployed	180,143	NA	NA	NA
35	Employed	187,821	138,188	NA	NA
35	Unemployed	179,026	131,309	NA	NA
45	Employed	178,038	135,841	123,523	129,493
45	Unemployed	168,768	128,623	117,275	122,916
55	Employed	166,898	123,883	109,811	115,735
55	Unemployed	154,681	114,408	101,795	107,162
65	Employed	156,384	113,508	79,536	87,963
65	Unemployed	156,384	113,508	79,536	87,963
75	Employed	104,850	74,697	52,276	58,228
75	Unemployed	104,850	74,697	52,276	58,228
85	Employed	53,428	39,692	32,851	36,755
85	Unemployed	53,428	39,692	32,851	36,755
Male; Caucasian; university certificate, diploma, or degree at bachelor level or above					
25	Employed	209,554	NA	NA	NA
25	Unemployed	201,180	NA	NA	NA
35	Employed	218,768	160,908	NA	NA
35	Unemployed	206,997	151,452	NA	NA
45	Employed	205,844	156,435	141,349	149,361
45	Unemployed	193,363	146,300	132,906	140,332
55	Employed	187,496	138,577	122,696	130,037
55	Unemployed	171,472	126,084	112,120	118,565
65	Employed	167,846	122,002	85,685	94,740
65	Unemployed	167,615	122,002	85,685	94,740
75	Employed	109,911	78,693	55,359	61,624
75	Unemployed	109,911	78,693	55,359	61,624
85	Employed	53,497	39,743	32,891	36,801
85	Unemployed	53,497	39,743	32,891	36,801

Table 43: Estimates of the value function for individuals with varying personal characteristics, by age, and health and employment status

Age	Employment Status	Healthy	Newly Diagnosed (Year 0)	T2DM, Poor Adherence (Year 9)	T2DM, Good Adherence (Year 9)
Male; Afro-Caribbean; no certificate, diploma or degree					
25	Employed	153,452	NA	NA	NA
25	Unemployed	147,532	NA	NA	NA
35	Employed	151,697	110,523	NA	NA
35	Unemployed	144,695	105,418	NA	NA
45	Employed	141,721	106,658	97,818	105,647
45	Unemployed	133,591	100,620	93,236	100,602
55	Employed	132,856	99,763	77,815	86,207
55	Unemployed	123,691	93,171	73,115	80,777
65	Employed	134,128	100,675	87,511	94,515
65	Unemployed	134,128	100,675	87,511	94,515
75	Employed	94,097	69,135	55,879	61,842
75	Unemployed	94,097	69,135	55,879	61,842
85	Employed	51,578	38,356	31,319	35,429
85	Unemployed	51,578	38,356	31,319	35,429
Male; Afro-Caribbean; high school diploma or equivalent					
25	Employed	166,190	NA	NA	NA
25	Unemployed	159,928	NA	NA	NA
35	Employed	164,551	119,990	NA	NA
35	Unemployed	156,778	114,174	NA	NA
45	Employed	149,595	112,578	103,068	111,436
45	Unemployed	141,737	106,668	98,589	106,517
55	Employed	141,035	105,968	82,379	91,358
55	Unemployed	132,025	99,347	77,682	85,934
65	Employed	141,442	106,203	92,189	99,558
65	Unemployed	141,442	106,203	92,189	99,558
75	Employed	97,770	71,947	58,077	64,255
75	Unemployed	97,770	71,947	58,077	64,255
85	Employed	52,087	38,753	31,601	35,748
85	Unemployed	52,087	38,753	31,601	35,748

Table 43: Estimates of the value function for individuals with varying personal characteristics, by age, and health and employment status					
Age	**Employment Status**	**Healthy**	**Newly Diagnosed (Year 0)**	**T2DM, Poor Adherence (Year 9)**	**T2DM, Good Adherence (Year 9)**
Male; Afro-Caribbean; post-secondary certificate or diploma below bachelor level					
25	Employed	183,258	NA	NA	NA
25	Unemployed	175,665	NA	NA	NA
35	Employed	181,815	137,141	NA	NA
35	Unemployed	173,030	130,355	NA	NA
45	Employed	169,532	129,952	119,856	128,941
45	Unemployed	160,289	122,827	114,061	122,631
55	Employed	160,432	122,878	96,627	106,598
55	Unemployed	148,274	113,556	89,499	98,514
65	Employed	151,959	116,188	101,826	109,397
65	Unemployed	151,959	116,188	101,826	109,397
75	Employed	102,797	77,454	63,267	69,618
75	Unemployed	102,797	77,454	63,267	69,618
85	Employed	52,829	40,351	33,346	37,532
85	Unemployed	52,829	40,351	33,346	37,532
Male; Afro-Caribbean; university certificate, diploma, or degree at bachelor level or above					
25	Employed	204,711	NA	NA	NA
25	Unemployed	196,345	NA	NA	NA
35	Employed	212,428	159,609	NA	NA
35	Unemployed	200,669	150,183	NA	NA
45	Employed	197,129	150,207	138,265	148,997
45	Unemployed	184,675	139,985	129,200	139,832
55	Employed	180,951	137,608	108,154	119,869
55	Unemployed	164,990	125,210	98,655	109,015
65	Employed	163,195	124,733	109,281	117,388
65	Unemployed	162,965	124,733	109,281	117,388
75	Employed	107,823	81,440	66,539	73,183
75	Unemployed	107,823	81,440	66,539	73,183
85	Employed	52,897	40,406	33,387	37,579
85	Unemployed	52,897	40,406	33,387	37,579

Table 43: Estimates of the value function for individuals with varying personal characteristics, by age, and health and employment status					
Age	**Employment Status**	**Healthy**	**Newly Diagnosed (Year 0)**	**T2DM, Poor Adherence (Year 9)**	**T2DM, Good Adherence (Year 9)**
Male; Asian-Indian; no certificate, diploma or degree					
25	Employed	153,820	NA	NA	NA
25	Unemployed	147,967	NA	NA	NA
35	Employed	151,759	106,952	NA	NA
35	Unemployed	144,854	101,926	NA	NA
45	Employed	141,281	104,336	96,414	105,172
45	Unemployed	133,243	98,384	91,998	100,211
55	Employed	132,221	89,554	74,480	83,769
55	Unemployed	123,182	83,116	70,083	78,534
65	Employed	133,492	97,851	86,896	94,856
65	Unemployed	133,492	97,851	86,896	94,856
75	Employed	93,914	62,401	49,898	56,241
75	Unemployed	93,914	62,401	49,898	56,241
85	Employed	51,685	37,400	29,738	34,586
85	Unemployed	51,685	37,400	29,738	34,586
Male; Asian-Indian; high school diploma or equivalent					
25	Employed	166,541	NA	NA	NA
25	Unemployed	160,331	NA	NA	NA
35	Employed	164,626	116,130	NA	NA
35	Unemployed	156,942	110,389	NA	NA
45	Employed	149,224	110,004	101,541	110,890
45	Unemployed	141,412	104,172	97,215	106,046
55	Employed	140,327	95,178	78,844	88,710
55	Unemployed	131,427	88,680	74,420	83,468
65	Employed	140,748	103,229	91,440	99,809
65	Unemployed	140,748	103,229	91,440	99,809
75	Employed	97,569	65,112	51,922	58,501
75	Unemployed	97,569	65,112	51,922	58,501
85	Employed	52,192	37,783	30,003	34,895
85	Unemployed	52,192	37,783	30,003	34,895

Table 43: Estimates of the value function for individuals with varying personal characteristics, by age, and health and employment status					
Age	**Employment Status**	**Healthy**	**Newly Diagnosed (Year 0)**	**T2DM, Poor Adherence (Year 9)**	**T2DM, Good Adherence (Year 9)**
Male; Asian-Indian; post-secondary certificate or diploma below bachelor level					
25	Employed	183,699	NA	NA	NA
25	Unemployed	176,166	NA	NA	NA
35	Employed	182,096	132,763	NA	NA
35	Unemployed	173,363	126,058	NA	NA
45	Employed	169,225	126,918	118,091	128,267
45	Unemployed	160,036	119,877	112,471	122,040
55	Employed	159,945	110,937	92,639	103,636
55	Unemployed	147,858	101,763	85,863	95,771
65	Employed	151,402	112,993	100,994	109,618
65	Unemployed	151,402	112,993	100,994	109,618
75	Employed	102,678	70,286	56,742	63,541
75	Unemployed	102,678	70,286	56,742	63,541
85	Employed	52,959	39,352	31,672	36,641
85	Unemployed	52,959	39,352	31,672	36,641
Male; Asian-Indian; university certificate, diploma, or degree at bachelor level or above					
25	Employed	205,197	NA	NA	NA
25	Unemployed	196,884	NA	NA	NA
35	Employed	212,580	154,723	NA	NA
35	Unemployed	200,886	145,343	NA	NA
45	Employed	196,717	146,450	135,833	148,209
45	Unemployed	184,332	136,498	127,324	139,028
55	Employed	180,418	124,459	103,776	116,584
55	Unemployed	164,542	112,432	94,683	105,986
65	Employed	162,612	121,326	108,229	117,458
65	Unemployed	162,389	121,326	108,229	117,458
75	Employed	107,711	74,205	59,794	66,920
75	Unemployed	107,711	74,205	59,794	66,920
85	Employed	53,027	39,405	31,711	36,686
85	Unemployed	53,027	39,405	31,711	36,686

Table 43: Estimates of the value function for individuals with varying personal characteristics, by age, and health and employment status					
Age	**Employment Status**	**Healthy**	**Newly Diagnosed (Year 0)**	**T2DM, Poor Adherence (Year 9)**	**T2DM, Good Adherence (Year 9)**
Female; Caucasian; no certificate, diploma or degree					
25	Employed	151,138	NA	NA	NA
25	Unemployed	147,308	NA	NA	NA
35	Employed	151,170	110,653	NA	NA
35	Unemployed	146,414	107,076	NA	NA
45	Employed	145,027	102,187	92,851	100,566
45	Unemployed	140,425	98,617	90,082	97,441
55	Employed	138,458	97,009	90,678	97,822
55	Unemployed	131,709	91,975	86,709	93,301
65	Employed	135,229	97,131	81,699	88,687
65	Unemployed	135,229	97,131	81,699	88,687
75	Employed	101,883	74,549	59,225	67,331
75	Unemployed	101,883	74,549	59,225	67,331
85	Employed	58,756	44,004	27,934	37,309
85	Unemployed	58,756	44,004	27,934	37,309
Female; Caucasian; high school diploma or equivalent					
25	Employed	161,183	NA	NA	NA
25	Unemployed	157,214	NA	NA	NA
35	Employed	162,213	118,391	NA	NA
35	Unemployed	157,698	114,973	NA	NA
45	Employed	159,931	112,792	102,165	110,575
45	Unemployed	154,669	108,759	98,905	106,963
55	Employed	152,431	107,421	99,761	107,628
55	Unemployed	146,055	102,534	95,801	103,235
65	Employed	142,591	102,657	86,275	93,646
65	Unemployed	142,591	102,657	86,275	93,646
75	Employed	106,551	78,190	62,070	70,538
75	Unemployed	106,551	78,190	62,070	70,538
85	Employed	59,291	44,404	28,169	37,622
85	Unemployed	59,291	44,404	28,169	37,622

Table 43: Estimates of the value function for individuals with varying personal characteristics, by age, and health and employment status					
Age	**Employment Status**	**Healthy**	**Newly Diagnosed (Year 0)**	**T2DM, Poor Adherence (Year 9)**	**T2DM, Good Adherence (Year 9)**
Female; Caucasian; post-secondary certificate or diploma below bachelor level					
25	Employed	172,432	NA	NA	NA
25	Unemployed	167,656	NA	NA	NA
35	Employed	174,031	127,554	NA	NA
35	Unemployed	168,283	122,988	NA	NA
45	Employed	168,512	118,718	113,138	116,326
45	Unemployed	162,580	114,126	109,073	112,175
55	Employed	160,216	112,584	109,529	112,793
55	Unemployed	153,252	107,200	104,751	107,917
65	Employed	150,883	108,361	94,355	98,654
65	Unemployed	150,883	108,361	94,355	98,654
75	Employed	111,629	82,134	67,475	73,831
75	Unemployed	111,629	82,134	67,475	73,831
85	Employed	59,986	45,578	29,608	38,119
85	Unemployed	59,986	45,578	29,608	38,119
Female; Caucasian; university certificate, diploma, or degree at bachelor level or above					
25	Employed	214,345	NA	NA	NA
25	Unemployed	206,755	NA	NA	NA
35	Employed	220,734	161,749	NA	NA
35	Unemployed	210,804	153,505	NA	NA
45	Employed	210,510	148,571	140,138	145,116
45	Unemployed	200,562	140,508	133,256	137,704
55	Employed	196,867	138,729	133,694	138,254
55	Unemployed	184,581	128,857	125,030	129,458
65	Employed	174,562	125,195	108,371	113,739
65	Unemployed	173,400	124,740	108,323	113,234
75	Employed	125,594	92,851	76,043	83,121
75	Unemployed	125,594	92,851	76,043	83,121
85	Employed	60,817	46,210	29,987	38,607
85	Unemployed	60,817	46,210	29,987	38,607

Table 43: Estimates of the value function for individuals with varying personal characteristics, by age, and health and employment status					
Age	**Employment Status**	**Healthy**	**Newly Diagnosed (Year 0)**	**T2DM, Poor Adherence (Year 9)**	**T2DM, Good Adherence (Year 9)**
Female; Afro-Caribbean; no certificate, diploma or degree					
25	Employed	148,488	NA	NA	NA
25	Unemployed	144,657	NA	NA	NA
35	Employed	148,024	106,861	NA	NA
35	Unemployed	143,270	103,436	NA	NA
45	Employed	141,078	102,455	93,376	100,194
45	Unemployed	136,483	99,149	90,856	97,374
55	Employed	134,479	98,974	88,909	95,577
55	Unemployed	127,754	94,331	85,350	91,527
65	Employed	130,634	97,726	85,039	93,177
65	Unemployed	130,634	97,726	85,039	93,177
75	Employed	99,389	72,336	63,278	69,401
75	Unemployed	99,389	72,336	63,278	69,401
85	Employed	57,949	43,257	34,805	41,007
85	Unemployed	57,949	43,257	34,805	41,007
Female; Afro-Caribbean; high school diploma or equivalent					
25	Employed	158,321	NA	NA	NA
25	Unemployed	154,351	NA	NA	NA
35	Employed	158,802	114,411	NA	NA
35	Unemployed	154,288	111,097	NA	NA
45	Employed	155,661	113,021	102,640	110,123
45	Unemployed	150,403	109,101	99,639	106,813
55	Employed	148,210	109,334	97,704	105,003
55	Unemployed	141,841	104,624	94,084	100,999
65	Employed	137,789	103,088	89,695	98,271
65	Unemployed	137,789	103,088	89,695	98,271
75	Employed	103,982	75,751	66,231	72,627
75	Unemployed	103,982	75,751	66,231	72,627
85	Employed	58,477	43,651	35,097	41,351
85	Unemployed	58,477	43,651	35,097	41,351

Table 43: Estimates of the value function for individuals with varying personal characteristics, by age, and health and employment status					
Age	**Employment Status**	**Healthy**	**Newly Diagnosed (Year 0)**	**T2DM, Poor Adherence (Year 9)**	**T2DM, Good Adherence (Year 9)**
Female; Afro-Caribbean; post-secondary certificate or diploma below bachelor level					
25	Employed	170,531	NA	NA	NA
25	Unemployed	165,754	NA	NA	NA
35	Employed	171,735	129,321	NA	NA
35	Unemployed	165,987	124,887	NA	NA
45	Employed	165,590	124,686	114,039	121,710
45	Unemployed	159,661	120,099	110,254	117,586
55	Employed	157,222	119,550	107,664	115,161
55	Unemployed	150,263	114,172	103,261	110,330
65	Employed	147,409	112,116	98,394	107,257
65	Unemployed	147,409	112,116	98,394	107,257
75	Employed	109,806	81,774	72,155	78,739
75	Unemployed	109,806	81,774	72,155	78,739
85	Employed	59,426	45,532	37,044	43,428
85	Unemployed	59,426	45,532	37,044	43,428
Female; Afro-Caribbean; university certificate, diploma, or degree at bachelor level or above					
25	Employed	212,012	NA	NA	NA
25	Unemployed	204,421	NA	NA	NA
35	Employed	217,949	164,234	NA	NA
35	Unemployed	208,021	155,820	NA	NA
45	Employed	207,022	155,650	141,619	151,578
45	Unemployed	197,078	147,419	134,450	144,184
55	Employed	193,429	147,012	131,028	140,885
55	Unemployed	181,149	136,854	123,031	132,157
65	Employed	170,693	129,847	112,636	123,218
65	Unemployed	169,542	129,173	112,636	122,759
75	Employed	123,646	92,614	81,048	88,404
75	Unemployed	123,646	92,614	81,048	88,404
85	Employed	60,249	46,163	37,518	43,984
85	Unemployed	60,249	46,163	37,518	43,984

Table 43: Estimates of the value function for individuals with varying personal characteristics, by age, and health and employment status					
Age	**Employment Status**	**Healthy**	**Newly Diagnosed (Year 0)**	**T2DM, Poor Adherence (Year 9)**	**T2DM, Good Adherence (Year 9)**
Female; Asian-Indian; no certificate, diploma or degree					
25	Employed	149,030	NA	NA	NA
25	Unemployed	145,265	NA	NA	NA
35	Employed	148,366	104,650	NA	NA
35	Unemployed	143,680	101,279	NA	NA
45	Employed	141,338	101,630	90,360	98,105
45	Unemployed	136,812	98,377	87,908	95,342
55	Employed	134,643	95,335	88,227	95,953
55	Unemployed	128,028	90,681	84,812	91,988
65	Employed	130,646	92,924	83,966	92,074
65	Unemployed	130,646	92,924	83,966	92,074
75	Employed	99,457	73,107	60,429	68,139
75	Unemployed	99,457	73,107	60,429	68,139
85	Employed	58,171	43,647	34,759	41,150
85	Unemployed	58,171	43,647	34,759	41,150
Female; Asian-Indian; high school diploma or equivalent					
25	Employed	158,818	NA	NA	NA
25	Unemployed	154,893	NA	NA	NA
35	Employed	159,072	111,961	NA	NA
35	Unemployed	154,620	108,695	NA	NA
45	Employed	155,833	112,095	99,363	107,821
45	Unemployed	150,641	108,226	96,431	104,566
55	Employed	148,303	105,319	96,857	105,313
55	Unemployed	142,012	100,671	93,338	101,367
65	Employed	137,763	98,081	88,560	97,100
65	Unemployed	137,763	98,081	88,560	97,100
75	Employed	104,031	76,635	63,288	71,335
75	Unemployed	104,031	76,635	63,288	71,335
85	Employed	58,696	44,041	35,073	41,492
85	Unemployed	58,696	44,041	35,073	41,492

Table 43: Estimates of the value function for individuals with varying personal characteristics, by age, and health and employment status					
Age	**Employment Status**	**Healthy**	**Newly Diagnosed (Year 0)**	**T2DM, Poor Adherence (Year 9)**	**T2DM, Good Adherence (Year 9)**
Female; Asian-Indian; post-secondary certificate or diploma below bachelor level					
25	Employed	171,010	NA	NA	NA
25	Unemployed	166,282	NA	NA	NA
35	Employed	172,011	126,607	NA	NA
35	Unemployed	166,330	122,226	NA	NA
45	Employed	165,790	123,647	110,406	119,190
45	Unemployed	159,928	119,114	106,700	115,128
55	Employed	157,352	115,203	106,929	115,484
55	Unemployed	150,472	109,892	102,464	110,717
65	Employed	147,432	106,788	97,152	105,990
65	Unemployed	147,432	106,788	97,152	105,990
75	Employed	109,897	82,764	69,029	77,385
75	Unemployed	109,897	82,764	69,029	77,385
85	Employed	59,654	45,977	37,051	43,578
85	Unemployed	59,654	45,977	37,051	43,578
Female; Asian-Indian; university certificate, diploma, or degree at bachelor level or above					
25	Employed	212,492	NA	NA	NA
25	Unemployed	204,957	NA	NA	NA
35	Employed	218,173	160,701	NA	NA
35	Unemployed	208,308	152,333	NA	NA
45	Employed	207,144	154,377	136,678	148,074
45	Unemployed	197,266	146,174	130,095	141,104
55	Employed	193,468	141,770	130,735	141,145
55	Unemployed	181,268	131,791	122,131	132,405
65	Employed	170,594	123,630	111,228	121,742
65	Unemployed	169,472	123,276	111,228	121,312
75	Employed	123,690	93,685	77,786	86,992
75	Unemployed	123,690	93,685	77,786	86,992
85	Employed	60,473	46,608	37,559	44,131
85	Unemployed	60,473	46,608	37,559	44,131

APPENDIX G: SENSITIVITY ANALYSIS AND ROBUSTNESS TEST DATA TABLES

Table 44: Characteristics of Optimal Policy (Female; Asian-Indian; Bachelor's degree or above)—Parameters: Unit Price of Consumption (p_c) and Substitution Parameter (ρ)

Value		Employment	Healthy			Newly Diagnosed				T2DM, Poor Adherence				T2DM, Good Adherence			
p_c	ρ		LTPA	Diet	LMP	LTPA	Diet	Meds	LMP	LTPA	Diet	Meds	LMP	LTPA	Diet	Meds	LMP
Age 25																	
0.50	-10	E	DA	DA	PT												
		U	DA	DA	FT												
	0	E	DA	DA	FT												
		U	DA	A	FT												
	1	E	DA	A	FT												
		U	DA	A	FT												
0.75	-10	E	DA	DA	PT												
		U	DA	DA	FT												
	0	E	DA	DA	FT												
		U	DA	A	FT												
	1	E	DA	A	FT												
		U	DA	A	FT												
1.00	-10	E	DA	DA	PT												
		U	DA	A	FT												
	0	E	DA	DA	FT												
		U	DA	A	FT												
	1	E	DA	A	FT												
		U	DA	A	FT												
1.50	-10	E	DA	DA	PT												
		U	DA	A	FT												
	0	E	DA	DA	FT												
		U	DA	A	FT												
	1	E	DA	A	FT												

Table 44: Characteristics of Optimal Policy (Female; Asian-Indian; Bachelor's degree or above)—Parameters: Unit Price of Consumption (p_c) and Substitution Parameter (ρ)

Value		Employment	Healthy			Newly Diagnosed				T2DM, Poor Adherence				T2DM, Good Adherence			
p_c	ρ		LTPA	Diet	LMP	LTPA	Diet	Meds	LMP	LTPA	Diet	Meds	LMP	LTPA	Diet	Meds	LMP
		U	DA	A	FT												
2.00	-10	E	DA	DA	PT												
		U	DA	A	FT												
	0	E	DA	DA	FT												
		U	DA	A	FT												
	1	E	DA	A	FT												
		U	DA	A	FT												
Age 35																	
0.50	-10	E	A	DA	PT	A	DA	A	PT								
		U	A	DA	FT	A	DA	A	FT								
	0	E	A	DA	FT	A	DA	A	FT								
		U	DA	A	FT	DA	A	A	FT								
	1	E	DA	A	FT	A	A	DA	FT								
		U	DA	A	FT	A	A	DA	FT								
0.75	-10	E	A	DA	PT	A	DA	A	PT								
		U	A	DA	FT	A	DA	A	FT								
	0	E	A	DA	FT	A	DA	A	FT								
		U	DA	A	FT	DA	A	A	FT								
	1	E	DA	A	FT	A	A	DA	FT								
		U	DA	A	FT	A	A	DA	FT								
1.00	-10	E	A	DA	PT	A	DA	A	PT								
		U	DA	A	FT	A	DA	A	FT								
	0	E	A	DA	FT	A	DA	A	FT								
		U	DA	A	FT	DA	A	A	FT								
	1	E	DA	A	FT	A	A	DA	FT								
		U	DA	A	FT	A	A	DA	FT								
1.50	-10	E	A	DA	PT	A	DA	A	PT								
		U	DA	A	FT	DA	A	A	FT								

Table 44: Characteristics of Optimal Policy (Female; Asian-Indian; Bachelor's degree or above)—Parameters: Unit Price of Consumption (p_c) and Substitution Parameter (ρ)

Value			Healthy			Newly Diagnosed				T2DM, Poor Adherence				T2DM, Good Adherence			
p_c	ρ	Employment	LTPA	Diet	LMP	LTPA	Diet	Meds	LMP	LTPA	Diet	Meds	LMP	LTPA	Diet	Meds	LMP
	0	E	A	DA	FT	A	DA	A	FT								
		U	DA	A	FT	DA	A	A	FT								
	1	E	DA	A	FT	A	A	DA	FT								
		U	DA	A	FT	A	A	DA	FT								
2.00	-10	E	A	DA	PT	A	DA	A	PT								
		U	DA	A	FT	DA	A	A	FT								
	0	E	A	DA	FT	A	DA	A	FT								
		U	DA	A	FT	DA	A	A	FT								
	1	E	DA	A	FT	A	A	DA	FT								
		U	DA	A	FT	A	A	DA	FT								
Age 45																	
0.50	-10	E	A	DA	PT	A	DA	A	PT	A	DA	A	PT	A	DA	A	PT
		U	A	DA	FT	A	DA	A	FT	A	DA	A	FT	A	DA	A	FT
	0	E	A	DA	FT	A	DA	A	FT	A	DA	DA	FT	DA	A	A	FT
		U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
	1	E	DA	A	FT	A	A	DA	FT	DA	A	DA	FT	A	A	DA	FT
		U	DA	A	FT	A	A	DA	FT	DA	A	DA	FT	A	A	DA	FT
0.75	-10	E	A	DA	PT	A	DA	A	PT	A	DA	A	PT	A	DA	A	PT
		U	A	DA	FT	A	DA	A	FT	A	DA	A	FT	A	DA	A	FT
	0	E	A	DA	FT	A	DA	A	FT	A	DA	DA	FT	DA	A	A	FT
		U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
	1	E	DA	A	FT	A	A	DA	FT	DA	A	DA	FT	A	A	DA	FT
		U	DA	A	FT	A	A	DA	FT	DA	A	DA	FT	A	A	DA	FT
1.00	-10	E	A	DA	PT	A	DA	A	PT	A	DA	A	PT	A	DA	A	PT
		U	DA	A	FT	A	DA	A	FT	A	DA	A	FT	A	DA	A	FT
	0	E	A	DA	FT	A	DA	A	FT	A	DA	DA	FT	DA	A	A	FT
		U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
	1	E	DA	A	FT	A	A	DA	FT	DA	A	DA	FT	A	A	DA	FT

Table 44: Characteristics of Optimal Policy (Female; Asian-Indian; Bachelor's degree or above)—Parameters: Unit Price of Consumption (p_c) and Substitution Parameter (ρ)

Value p_c	Value ρ	Employment	Healthy LTPA	Healthy Diet	Healthy LMP	Newly Diagnosed LTPA	Newly Diagnosed Diet	Newly Diagnosed Meds	Newly Diagnosed LMP	T2DM, Poor Adherence LTPA	T2DM, Poor Adherence Diet	T2DM, Poor Adherence Meds	T2DM, Poor Adherence LMP	T2DM, Good Adherence LTPA	T2DM, Good Adherence Diet	T2DM, Good Adherence Meds	T2DM, Good Adherence LMP
		U	DA	A	FT	A	A	DA	FT	DA	A	DA	FT	A	A	DA	FT
1.50	-10	E	A	DA	PT	A	DA	A	PT	A	DA	A	PT	A	DA	A	PT
		U	DA	A	FT	DA	A	A	FT	A	DA	A	FT	A	DA	A	FT
	0	E	A	DA	FT	A	DA	A	FT	A	DA	DA	FT	DA	A	A	FT
		U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
	1	E	DA	A	FT	A	A	DA	FT	DA	A	DA	FT	A	A	DA	FT
		U	DA	A	FT	A	A	DA	FT	DA	A	DA	FT	A	A	DA	FT
2.00	-10	E	A	DA	PT	A	DA	A	PT	A	DA	A	PT	A	DA	A	PT
		U	DA	A	FT	DA	A	A	FT	A	DA	A	FT	A	DA	A	FT
	0	E	A	DA	FT	A	DA	A	FT	A	DA	DA	FT	DA	A	A	FT
		U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
	1	E	DA	A	FT	A	A	DA	FT	DA	A	DA	FT	A	A	DA	FT
		U	DA	A	FT	A	A	DA	FT	DA	A	DA	FT	DA	A	A	FT
Age 55																	
0.50	-10	E	A	DA	PT	A	DA	A	PT	A	DA	A	PT	A	DA	A	PT
		U	A	DA	FT	A	DA	A	FT	A	DA	A	FT	A	DA	A	FT
	0	E	A	DA	FT	A	DA	A	FT	A	DA	DA	FT	A	DA	A	FT
		U	DA	A	FT	DA	A	A	FT	DA	A	DA	FT	DA	A	A	FT
	1	E	DA	A	FT	A	A	DA	FT	DA	A	DA	FT	DA	A	DA	FT
		U	DA	A	FT	A	A	DA	FT	DA	A	DA	FT	DA	A	DA	FT
0.75	-10	E	A	DA	PT	A	DA	A	PT	A	DA	A	PT	A	DA	A	PT
		U	A	DA	FT	A	DA	A	FT	A	DA	A	FT	A	DA	A	FT
	0	E	A	DA	FT	A	DA	A	FT	A	DA	DA	FT	A	DA	A	FT
		U	DA	A	FT	DA	A	A	FT	DA	A	DA	FT	DA	A	A	FT
	1	E	DA	A	FT	A	A	DA	FT	DA	A	DA	FT	DA	A	DA	FT
		U	DA	A	FT	A	A	DA	FT	DA	A	DA	FT	DA	A	DA	FT
1.00	-10	E	A	DA	PT	A	DA	A	PT	A	DA	A	PT	A	DA	A	PT
		U	DA	A	FT	A	DA	A	FT	A	DA	A	FT	A	DA	A	FT

Table 44: Characteristics of Optimal Policy (Female; Asian-Indian; Bachelor's degree or above)—Parameters: Unit Price of Consumption (p_c) and Substitution Parameter (ρ)																	
Value		**Employment**	**Healthy**			**Newly Diagnosed**				**T2DM, Poor Adherence**				**T2DM, Good Adherence**			
p_c	**ρ**		**LTPA**	**Diet**	**LMP**	**LTPA**	**Diet**	**Meds**	**LMP**	**LTPA**	**Diet**	**Meds**	**LMP**	**LTPA**	**Diet**	**Meds**	**LMP**
	0	E	A	DA	FT	A	DA	A	FT	A	DA	DA	FT	A	DA	A	FT
		U	DA	A	FT	DA	A	A	FT	DA	A	DA	FT	DA	A	A	FT
	1	E	DA	A	FT	A	A	DA	FT	DA	A	DA	FT	DA	A	DA	FT
		U	DA	A	FT	A	A	DA	FT	DA	A	DA	FT	DA	A	DA	FT
1.50	-10	E	A	DA	PT	A	DA	A	PT	A	DA	A	PT	A	DA	A	PT
		U	DA	A	FT	DA	A	A	FT	A	DA	A	FT	A	DA	A	FT
	0	E	A	DA	FT	A	DA	A	FT	A	DA	DA	FT	A	DA	A	FT
		U	DA	A	FT	DA	A	A	FT	DA	A	DA	FT	DA	A	A	FT
	1	E	DA	A	FT	A	A	DA	FT	DA	A	DA	FT	DA	A	DA	FT
		U	DA	A	FT	A	A	DA	FT	DA	A	DA	FT	DA	A	DA	FT
2.00	-10	E	A	DA	PT	A	DA	A	PT	A	DA	A	PT	A	DA	A	PT
		U	DA	A	FT	DA	A	A	FT	A	DA	A	FT	A	DA	A	FT
	0	E	A	DA	FT	A	DA	A	FT	A	DA	DA	FT	A	DA	A	FT
		U	DA	A	FT	DA	A	A	FT	DA	A	DA	FT	DA	A	A	FT
	1	E	DA	A	FT	A	A	DA	FT	DA	A	DA	FT	DA	A	DA	FT
		U	DA	A	FT	A	A	DA	FT	DA	A	DA	FT	DA	A	DA	FT
Age 65																	
0.50	-10	E	A	DA	RT	A	DA	A	RT	A	DA	A	RT	A	DA	A	RT
		U	A	DA	RT	A	DA	A	RT	A	DA	A	RT	A	DA	A	RT
	0	E	A	DA	FT	DA	A	A	FT	DA	A	A	RT	DA	A	A	FT
		U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
	1	E	DA	A	FT	A	A	DA	FT	DA	A	DA	FT	DA	A	DA	FT
		U	DA	A	RT	A	A	DA	RT	DA	A	DA	RT	DA	A	DA	RT
0.75	-10	E	A	DA	RT	A	DA	A	RT	A	DA	A	RT	A	DA	A	RT
		U	A	DA	RT	A	DA	A	RT	A	DA	A	RT	A	DA	A	RT
	0	E	A	DA	FT	DA	A	A	FT	DA	A	A	RT	DA	A	A	FT
		U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
	1	E	DA	A	FT	A	A	DA	FT	DA	A	DA	FT	DA	A	DA	FT

Table 44: Characteristics of Optimal Policy (Female; Asian-Indian; Bachelor's degree or above)—Parameters: Unit Price of Consumption (p_c) and Substitution Parameter (ρ)

Value		Employment	Healthy			Newly Diagnosed				T2DM, Poor Adherence				T2DM, Good Adherence			
p_c	ρ		LTPA	Diet	LMP	LTPA	Diet	Meds	LMP	LTPA	Diet	Meds	LMP	LTPA	Diet	Meds	LMP
		U	DA	A	RT	A	A	DA	RT	DA	A	DA	RT	DA	A	DA	RT
1.00	-10	E	A	DA	RT	A	DA	A	RT	A	DA	A	RT	A	DA	A	RT
		U	A	DA	RT	A	DA	A	RT	A	DA	A	RT	A	DA	A	RT
	0	E	A	DA	FT	DA	A	A	FT	DA	A	A	RT	DA	A	A	FT
		U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
	1	E	DA	A	FT	A	A	DA	FT	DA	A	DA	FT	DA	A	DA	FT
		U	DA	A	RT	A	A	DA	RT	DA	A	DA	RT	DA	A	DA	RT
1.50	-10	E	A	DA	RT	A	DA	A	RT	A	DA	A	RT	A	DA	A	RT
		U	A	DA	RT	A	DA	A	RT	A	DA	A	RT	A	DA	A	RT
	0	E	A	DA	FT	DA	A	A	FT	DA	A	A	RT	DA	A	A	FT
		U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
	1	E	DA	A	FT	A	A	DA	FT	DA	A	DA	FT	DA	A	DA	FT
		U	DA	A	RT	A	A	DA	RT	DA	A	DA	RT	DA	A	DA	RT
2.00	-10	E	A	DA	RT	A	DA	A	RT	A	DA	A	RT	A	DA	A	RT
		U	A	DA	RT	A	DA	A	RT	A	DA	A	RT	A	DA	A	RT
	0	E	A	DA	FT	DA	A	A	FT	DA	A	A	RT	DA	A	A	FT
		U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
	1	E	DA	A	FT	A	A	DA	FT	DA	A	DA	FT	DA	A	DA	FT
		U	DA	A	RT	A	A	DA	RT	DA	A	DA	RT	DA	A	DA	RT
Age 75																	
0.50	-10	E	A	DA	RT	A	DA	A	RT	A	DA	A	RT	A	DA	A	RT
		U	A	DA	RT	A	DA	A	RT	A	DA	A	RT	A	DA	A	RT
	0	E	DA	A	RT	DA	A	A	RT	DA	A	DA	RT	DA	A	A	RT
		U	DA	A	RT	DA	A	A	RT	DA	A	DA	RT	DA	A	A	RT
	1	E	DA	A	FT	A	A	DA	FT	DA	A	DA	FT	DA	A	DA	FT
		U	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	DA	RT
0.75	-10	E	A	DA	RT	A	DA	A	RT	A	DA	A	RT	A	DA	A	RT
		U	A	DA	RT	A	DA	A	RT	A	DA	A	RT	A	DA	A	RT

Table 44: Characteristics of Optimal Policy (Female; Asian-Indian; Bachelor's degree or above)—Parameters: Unit Price of Consumption (p_c) and Substitution Parameter (ρ)

Value		Employment	Healthy			Newly Diagnosed				T2DM, Poor Adherence				T2DM, Good Adherence			
p_c	ρ		LTPA	Diet	LMP	LTPA	Diet	Meds	LMP	LTPA	Diet	Meds	LMP	LTPA	Diet	Meds	LMP
	0	E	DA	A	RT	DA	A	A	RT	DA	A	DA	RT	DA	A	A	RT
		U	DA	A	RT	DA	A	A	RT	DA	A	DA	RT	DA	A	A	RT
	1	E	DA	A	FT	A	A	DA	FT	DA	A	DA	FT	DA	A	DA	FT
		U	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	DA	RT
1.00	-10	E	A	DA	RT	A	DA	A	RT	A	DA	A	RT	A	DA	A	RT
		U	A	DA	RT	A	DA	A	RT	A	DA	A	RT	A	DA	A	RT
	0	E	DA	A	RT	DA	A	A	RT	DA	A	DA	RT	DA	A	A	RT
		U	DA	A	RT	DA	A	A	RT	DA	A	DA	RT	DA	A	A	RT
	1	E	DA	A	FT	A	A	DA	FT	DA	A	DA	FT	DA	A	DA	FT
		U	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	DA	RT
1.50	-10	E	A	DA	RT	A	DA	A	RT	A	DA	A	RT	A	DA	A	RT
		U	A	DA	RT	A	DA	A	RT	A	DA	A	RT	A	DA	A	RT
	0	E	DA	A	RT	DA	A	A	RT	DA	A	DA	RT	DA	A	A	RT
		U	DA	A	RT	DA	A	A	RT	DA	A	DA	RT	DA	A	A	RT
	1	E	DA	A	FT	A	A	DA	FT	DA	A	DA	FT	DA	A	DA	FT
		U	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	DA	RT
2.00	-10	E	A	DA	RT	A	DA	A	RT	A	DA	A	RT	A	DA	A	RT
		U	A	DA	RT	A	DA	A	RT	A	DA	A	RT	A	DA	A	RT
	0	E	DA	A	RT	DA	A	A	RT	DA	A	DA	RT	DA	A	A	RT
		U	DA	A	RT	DA	A	A	RT	DA	A	DA	RT	DA	A	A	RT
	1	E	DA	A	FT	A	A	DA	FT	DA	A	DA	FT	DA	A	DA	FT
		U	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	DA	RT
Age 85																	
0.50	-10	E	A	DA	RT	A	DA	A	RT	A	DA	A	RT	A	DA	A	RT
		U	A	DA	RT	A	DA	A	RT	A	DA	A	RT	A	DA	A	RT
	0	E	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	A	RT
		U	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	A	RT
	1	E	DA	A	FT	DA	A	DA	FT	DA	A	DA	FT	DA	A	DA	FT

Table 44: Characteristics of Optimal Policy (Female; Asian-Indian; Bachelor's degree or above)—Parameters: Unit Price of Consumption (p_c) and Substitution Parameter (ρ)

Value		Employment	Healthy			Newly Diagnosed				T2DM, Poor Adherence				T2DM, Good Adherence			
p_c	ρ		LTPA	Diet	LMP	LTPA	Diet	Meds	LMP	LTPA	Diet	Meds	LMP	LTPA	Diet	Meds	LMP
		U	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	DA	RT
0.75	-10	E	A	DA	RT	A	DA	A	RT	A	DA	A	RT	A	DA	A	RT
		U	A	DA	RT	A	DA	A	RT	A	DA	A	RT	A	DA	A	RT
	0	E	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	A	RT
		U	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	A	RT
	1	E	DA	A	FT	DA	A	DA	FT	DA	A	DA	RT	DA	A	DA	FT
		U	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	DA	RT
1.00	-10	E	A	DA	RT	A	DA	A	RT	A	DA	A	RT	A	DA	A	RT
		U	A	DA	RT	A	DA	A	RT	A	DA	A	RT	A	DA	A	RT
	0	E	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	A	RT
		U	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	A	RT
	1	E	DA	A	FT	DA	A	DA	FT	DA	A	DA	RT	DA	A	DA	FT
		U	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	DA	RT
1.50	-10	E	A	DA	RT	A	DA	A	RT	A	DA	A	RT	A	DA	A	RT
		U	A	DA	RT	A	DA	A	RT	A	DA	A	RT	A	DA	A	RT
	0	E	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	A	RT
		U	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	A	RT
	1	E	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	DA	RT
		U	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	DA	RT
2.00	-10	E	A	DA	RT	A	DA	A	RT	A	DA	A	RT	A	DA	A	RT
		U	A	DA	RT	A	DA	A	RT	A	DA	A	RT	A	DA	A	RT
	0	E	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	A	RT
		U	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	A	RT
	1	E	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	DA	RT
		U	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	DA	RT

Table 45: Characteristics of Optimal Policy (Female; Asian-Indian; Bachelor's degree or above)—Parameter: α (i.e., preference for consumption relative to leisure)

Value	**Employment Status**	**Healthy**			**Newly Diagnosed**				**T2DM, Poor Adherence**				**T2DM, Good Adherence**			
		LTPA	**Diet**	**LMP**	**LTPA**	**Diet**	**Meds**	**LMP**	**LTPA**	**Diet**	**Meds**	**LMP**	**LTPA**	**Diet**	**Meds**	**LMP**
Age 25																
0	E	DA	DA	PT												
0	U	DA	DA	FT												
0.25	E	DA	DA	FT												
0.25	U	DA	A	FT												
0.5	E	DA	DA	FT												
0.5	U	DA	A	FT												
0.75	E	DA	A	FT												
0.75	U	DA	A	FT												
1	E	A	A	FT												
1	U	A	A	FT												
Age 35																
0	E	A	DA	PT	A	DA	A	PT								
0	U	A	DA	FT	A	DA	A	FT								
0.25	E	A	DA	FT	A	DA	A	FT								
0.25	U	DA	A	FT	A	DA	A	FT								
0.5	E	A	DA	FT	A	DA	A	FT								
0.5	U	DA	A	FT	DA	A	A	FT								
0.75	E	DA	A	FT	A	A	DA	FT								
0.75	U	DA	A	FT	A	A	DA	FT								
1	E	A	A	FT	A	A	DA	FT								
1	U	A	A	FT	A	A	DA	FT								
Age 45																
0	E	A	DA	PT	A	DA	A	PT	A	DA	A	PT	A	DA	A	PT
0	U	A	DA	FT	A	DA	A	FT	A	DA	A	FT	A	DA	A	FT
0.25	E	A	DA	FT	A	DA	A	FT	A	DA	A	FT	A	DA	A	FT
0.25	U	DA	A	FT	A	DA	A	FT	A	DA	A	FT	A	DA	A	FT
0.5	E	A	DA	FT	A	DA	A	FT	A	DA	DA	FT	DA	A	A	FT
0.5	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT

Table 45: Characteristics of Optimal Policy (Female; Asian-Indian; Bachelor's degree or above)—Parameter: α (i.e., preference for consumption relative to leisure)

Value	Employment Status	Healthy			Newly Diagnosed				T2DM, Poor Adherence				T2DM, Good Adherence			
		LTPA	Diet	LMP	LTPA	Diet	Meds	LMP	LTPA	Diet	Meds	LMP	LTPA	Diet	Meds	LMP
0.75	E	DA	A	FT	A	A	DA	FT	DA	A	DA	FT	DA	A	A	FT
0.75	U	DA	A	FT	A	A	DA	FT	DA	A	DA	FT	DA	A	A	FT
1	E	A	A	FT	A	A	DA	FT	DA	A	DA	FT	A	A	DA	FT
1	U	A	A	FT	A	A	DA	FT	DA	A	DA	FT	DA	A	DA	FT
Age 55																
0	E	A	DA	PT	A	DA	A	PT	A	DA	A	PT	A	DA	A	PT
0	U	A	DA	FT	A	DA	A	FT	A	DA	A	FT	A	DA	A	FT
0.25	E	A	DA	FT	A	DA	A	FT	A	DA	A	FT	A	DA	A	FT
0.25	U	DA	A	FT	A	DA	A	FT	A	DA	A	FT	A	DA	A	FT
0.5	E	A	DA	FT	A	DA	A	FT	A	DA	DA	FT	A	DA	A	FT
0.5	U	DA	A	FT	DA	A	A	FT	DA	A	DA	FT	DA	A	A	FT
0.75	E	DA	A	FT	A	A	DA	FT	DA	A	DA	FT	A	A	DA	FT
0.75	U	DA	A	FT	A	A	DA	FT	DA	A	DA	FT	DA	A	A	FT
1	E	A	A	FT	A	A	DA	FT	DA	A	DA	FT	DA	A	DA	FT
1	U	A	A	FT	A	A	DA	FT	DA	A	DA	FT	DA	A	DA	FT
Age 65																
0	E	A	DA	RT	A	DA	A	RT	A	DA	A	RT	A	DA	A	RT
0	U	A	DA	RT	A	DA	A	RT	A	DA	A	RT	A	DA	A	RT
0.25	E	A	DA	RT	A	DA	A	RT	A	DA	A	RT	A	DA	A	RT
0.25	U	A	DA	RT	A	DA	A	RT	A	DA	A	RT	A	DA	A	RT
0.5	E	A	DA	FT	DA	A	A	FT	DA	A	A	RT	DA	A	A	FT
0.5	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
0.75	E	DA	A	FT	DA	A	A	FT	DA	A	DA	FT	DA	A	A	FT
0.75	U	DA	A	RT	A	A	DA	RT	DA	A	DA	RT	DA	A	DA	RT
1	E	A	A	FT	A	A	DA	FT	DA	A	DA	FT	DA	A	DA	FT
1	U	A	A	RT	A	A	DA	RT	DA	A	DA	RT	DA	A	DA	RT
Age 75																
0	E	A	DA	RT	A	DA	A	RT	A	DA	A	RT	A	DA	A	RT
0	U	A	DA	RT	A	DA	A	RT	A	DA	A	RT	A	DA	A	RT

Table 45: Characteristics of Optimal Policy (Female; Asian-Indian; Bachelor's degree or above)—Parameter: α (i.e., preference for consumption relative to leisure)																
Value	**Employment Status**	**Healthy**			**Newly Diagnosed**				**T2DM, Poor Adherence**				**T2DM, Good Adherence**			
		LTPA	**Diet**	**LMP**	**LTPA**	**Diet**	**Meds**	**LMP**	**LTPA**	**Diet**	**Meds**	**LMP**	**LTPA**	**Diet**	**Meds**	**LMP**
0.25	E	A	DA	RT	A	DA	A	RT	A	DA	A	RT	A	DA	A	RT
0.25	U	A	DA	RT	A	DA	A	RT	A	DA	A	RT	A	DA	A	RT
0.5	E	DA	A	RT	DA	A	A	RT	DA	A	DA	RT	DA	A	A	RT
0.5	U	DA	A	RT	DA	A	A	RT	DA	A	DA	RT	DA	A	A	RT
0.75	E	DA	A	FT	DA	A	A	FT	DA	A	DA	FT	DA	A	DA	FT
0.75	U	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	DA	RT
1	E	A	A	FT	A	A	DA	FT	DA	A	DA	FT	DA	A	DA	FT
1	U	A	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	DA	RT
Age 85																
0	E	A	DA	RT	A	DA	A	RT	A	DA	A	RT	A	DA	A	RT
0	U	A	DA	RT	A	DA	A	RT	A	DA	A	RT	A	DA	A	RT
0.25	E	A	DA	RT	A	DA	A	RT	A	DA	A	RT	A	DA	A	RT
0.25	U	A	DA	RT	A	DA	A	RT	A	DA	A	RT	A	DA	A	RT
0.5	E	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	A	RT
0.5	U	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	A	RT
0.75	E	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	DA	RT
0.75	U	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	DA	RT
1	E	A	A	FT	DA	A	DA	FT	DA	A	DA	FT	DA	A	DA	FT
1	U	A	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	DA	RT

Table 46: Characteristics of Optimal Policy (Female; Asian-Indian; Bachelor's degree or above)—Parameter: Discount Factor																	
Value	**Employment Status**	**Healthy**			**Newly Diagnosed**				**T2DM, Poor Adherence**				**T2DM, Good Adherence**				
		LTPA	**Diet**	**LMP**	**LTPA**	**Diet**	**Meds**	**LMP**	**LTPA**	**Diet**	**Meds**	**LMP**	**LTPA**	**Diet**	**Meds**	**LMP**	
Age 25																	
0	E	DA	DA	FT													
0	U	DA	A	FT													
0.5	E	DA	DA	FT													
0.5	U	DA	A	FT													
0.75	E	DA	DA	FT													
0.75	U	DA	A	FT													
0.9	E	DA	DA	FT													
0.9	U	DA	A	FT													
1	E	DA	DA	FT													
1	U	DA	A	FT													
Age 35																	
0	E	DA	DA	FT	DA	DA	DA	FT									
0	U	DA	A	FT	DA	A	A	FT									
0.5	E	DA	DA	FT	DA	DA	DA	FT									
0.5	U	DA	A	FT	DA	A	A	FT									
0.75	E	A	DA	FT	DA	DA	DA	FT									
0.75	U	DA	A	FT	DA	A	A	FT									
0.9	E	A	DA	FT	A	DA	A	FT									
0.9	U	DA	A	FT	DA	A	A	FT									
1	E	A	DA	FT	A	DA	A	FT									
1	U	DA	A	FT	DA	A	A	FT									
Age 45																	
0	E	DA	DA	FT	DA	DA	DA	FT	DA	DA	DA	FT	DA	DA	DA	FT	
0	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT	
0.5	E	A	DA	FT	DA	DA	DA	FT	DA	DA	DA	FT	DA	DA	DA	FT	
0.5	U	DA	A	FT	DA	A	A	FT	DA	A	DA	FT	DA	A	DA	FT	
0.75	E	A	DA	FT	DA	DA	DA	FT	DA	DA	DA	FT	DA	DA	DA	FT	
0.75	U	DA	A	FT	DA	A	A	FT	DA	A	DA	FT	A	A	DA	FT	

Table 46: Characteristics of Optimal Policy (Female; Asian-Indian; Bachelor's degree or above)—Parameter: Discount Factor																	
Value	**Employment Status**	**Healthy**			**Newly Diagnosed**				**T2DM, Poor Adherence**				**T2DM, Good Adherence**			
		LTPA	**Diet**	**LMP**	**LTPA**	**Diet**	**Meds**	**LMP**	**LTPA**	**Diet**	**Meds**	**LMP**	**LTPA**	**Diet**	**Meds**	**LMP**
0.9	E	A	DA	FT	A	DA	A	FT	A	DA	DA	FT	DA	A	A	FT
0.9	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
1	E	A	DA	FT	A	DA	A	FT	DA	A	A	FT	DA	A	A	FT
1	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
Age 55																
0	E	DA	DA	FT	DA	DA	DA	FT	DA	DA	DA	FT	DA	DA	DA	FT
0	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
0.5	E	A	DA	FT	DA	DA	DA	FT	DA	DA	DA	FT	DA	DA	DA	FT
0.5	U	DA	A	FT	DA	A	A	FT	DA	A	DA	FT	DA	A	DA	FT
0.75	E	A	DA	FT	A	DA	A	FT	DA	DA	DA	FT	DA	DA	DA	FT
0.75	U	DA	A	FT	DA	A	A	FT	DA	A	DA	FT	A	A	DA	FT
0.9	E	A	DA	FT	A	DA	A	FT	A	DA	DA	FT	A	DA	A	FT
0.9	U	DA	A	FT	DA	A	A	FT	DA	A	DA	FT	DA	A	A	FT
1	E	A	DA	FT	A	DA	A	FT	DA	A	A	FT	DA	A	A	FT
1	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
Age 65																
0	E	DA	DA	FT	DA	DA	DA	FT	DA	DA	DA	FT	DA	DA	DA	FT
0	U	DA	DA	RT	DA	DA	DA	RT	DA	DA	DA	RT	DA	DA	DA	RT
0.5	E	DA	DA	FT	DA	DA	DA	FT	DA	DA	DA	FT	DA	DA	DA	FT
0.5	U	DA	A	RT	DA	DA	DA	RT	DA	DA	DA	RT	DA	DA	DA	RT
0.75	E	A	DA	FT	A	DA	A	FT	A	DA	DA	FT	DA	DA	DA	FT
0.75	U	DA	A	RT	DA	A	A	RT	DA	A	DA	RT	DA	A	DA	RT
0.9	E	A	DA	FT	DA	A	A	FT	DA	A	A	RT	DA	A	A	FT
0.9	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
1	E	A	DA	FT	DA	A	A	FT	DA	A	A	RT	DA	A	A	FT
1	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
Age 75																
0	E	DA	DA	RT	DA	DA	DA	RT	DA	DA	DA	RT	DA	DA	DA	RT
0	U	DA	DA	RT	DA	DA	DA	RT	DA	DA	DA	RT	DA	DA	DA	RT

Table 46: Characteristics of Optimal Policy (Female; Asian-Indian; Bachelor's degree or above)—Parameter: Discount Factor

Value	Employment Status	Healthy			Newly Diagnosed				T2DM, Poor Adherence				T2DM, Good Adherence			
		LTPA	Diet	LMP	LTPA	Diet	Meds	LMP	LTPA	Diet	Meds	LMP	LTPA	Diet	Meds	LMP
0.5	E	DA	A	RT	DA	DA	DA	RT	DA	DA	DA	RT	DA	A	DA	RT
0.5	U	DA	A	RT	DA	DA	DA	RT	DA	DA	DA	RT	DA	A	DA	RT
0.75	E	DA	A	RT	DA	A	A	RT	DA	A	DA	RT	DA	A	DA	RT
0.75	U	DA	A	RT	DA	A	A	RT	DA	A	DA	RT	DA	A	DA	RT
0.9	E	DA	A	RT	DA	A	A	RT	DA	A	DA	RT	DA	A	A	RT
0.9	U	DA	A	RT	DA	A	A	RT	DA	A	DA	RT	DA	A	A	RT
1	E	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
1	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
Age 85																
0	E	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	DA	RT
0	U	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	DA	RT
0.5	E	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	DA	RT
0.5	U	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	DA	RT
0.75	E	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	DA	RT
0.75	U	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	DA	RT
0.9	E	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	A	RT
0.9	U	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	A	RT
1	E	DA	A	RT	DA	A	A	RT	DA	A	DA	RT	DA	A	A	RT
1	U	DA	A	RT	DA	A	A	RT	DA	A	DA	RT	DA	A	A	RT

Table 47: Characteristics of Optimal Policy (Female; Asian-Indian; Bachelor's degree or above)—Parameter: Age-Related Productivity Decline																
Value	**Employment Status**	**Healthy**			**Newly Diagnosed**				**T2DM, Poor Adherence**				**T2DM, Good Adherence**			
		LTPA	**Diet**	**LMP**	**LTPA**	**Diet**	**Meds**	**LMP**	**LTPA**	**Diet**	**Meds**	**LMP**	**LTPA**	**Diet**	**Meds**	**LMP**
Age 25																
0.0%	E	DA	DA	FT												
0.0%	U	DA	A	FT												
1.0%	E	DA	DA	FT												
1.0%	U	DA	A	FT												
2.5%	E	DA	DA	FT												
2.5%	U	DA	A	FT												
5.0%	E	DA	DA	FT												
5.0%	U	DA	A	FT												
10.0%	E	DA	DA	FT												
10.0%	U	DA	A	FT												
Age 35																
0.0%	E	A	DA	FT	A	DA	A	FT								
0.0%	U	DA	A	FT	DA	A	A	FT								
1.0%	E	A	DA	FT	A	DA	A	FT								
1.0%	U	DA	A	FT	DA	A	A	FT								
2.5%	E	A	DA	FT	A	DA	A	FT								
2.5%	U	DA	A	FT	DA	A	A	FT								
5.0%	E	A	DA	FT	A	DA	A	FT								
5.0%	U	DA	A	FT	DA	A	A	FT								
10.0%	E	A	DA	FT	A	DA	A	FT								
10.0%	U	DA	A	FT	DA	A	A	FT								
Age 45																
0.0%	E	A	DA	FT	A	DA	A	FT	A	DA	A	FT	A	DA	A	FT
0.0%	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
1.0%	E	A	DA	FT	A	DA	A	FT	A	DA	DA	FT	A	DA	A	FT
1.0%	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
2.5%	E	A	DA	FT	A	DA	A	FT	A	DA	DA	FT	DA	A	A	FT
2.5%	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT

Table 47: Characteristics of Optimal Policy (Female; Asian-Indian; Bachelor's degree or above)—Parameter: Age-Related Productivity Decline																
Value	**Employment Status**	**Healthy**			**Newly Diagnosed**				**T2DM, Poor Adherence**				**T2DM, Good Adherence**			
		LTPA	**Diet**	**LMP**	**LTPA**	**Diet**	**Meds**	**LMP**	**LTPA**	**Diet**	**Meds**	**LMP**	**LTPA**	**Diet**	**Meds**	**LMP**
5.0%	E	A	DA	FT	A	DA	A	FT	A	DA	DA	FT	DA	A	A	FT
5.0%	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
10.0%	E	A	DA	FT	A	DA	A	FT	A	DA	DA	FT	DA	A	A	FT
10.0%	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
Age 55																
0.0%	E	A	DA	FT	A	DA	A	FT	A	DA	DA	FT	A	DA	A	FT
0.0%	U	DA	A	FT	DA	A	A	FT	DA	A	DA	FT	DA	A	A	FT
1.0%	E	A	DA	FT	A	DA	A	FT	A	DA	DA	FT	A	DA	A	FT
1.0%	U	DA	A	FT	DA	A	A	FT	DA	A	DA	FT	DA	A	A	FT
2.5%	E	A	DA	FT	A	DA	A	FT	A	DA	DA	FT	A	DA	A	FT
2.5%	U	DA	A	FT	DA	A	A	FT	DA	A	DA	FT	DA	A	A	FT
5.0%	E	A	DA	FT	A	DA	A	FT	A	DA	DA	FT	DA	A	A	FT
5.0%	U	DA	A	FT	DA	A	A	FT	DA	A	DA	FT	DA	A	A	FT
10.0%	E	A	DA	FT	A	DA	A	FT	A	DA	DA	FT	DA	A	A	FT
10.0%	U	DA	A	FT	DA	A	A	FT	DA	A	DA	FT	DA	A	A	FT
Age 65																
0.0%	E	A	DA	FT	A	DA	A	FT	A	DA	A	FT	A	DA	A	FT
0.0%	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
1.0%	E	A	DA	FT	A	DA	A	FT	DA	A	A	RT	DA	A	A	FT
1.0%	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
2.5%	E	A	DA	FT	DA	A	A	FT	DA	A	A	RT	DA	A	A	FT
2.5%	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
5.0%	E	A	DA	FT	DA	A	A	FT	DA	A	A	RT	DA	A	A	FT
5.0%	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
10.0%	E	A	DA	FT	DA	A	A	FT	DA	A	A	RT	DA	A	A	FT
10.0%	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
Age 75																
0.0%	E	A	DA	FT	A	DA	A	FT	A	DA	DA	FT	A	DA	A	FT
0.0%	U	DA	A	RT	DA	A	A	RT	DA	A	DA	RT	DA	A	A	RT

Table 47: Characteristics of Optimal Policy (Female; Asian-Indian; Bachelor's degree or above)—Parameter: Age-Related Productivity Decline

Value	Employment Status	Healthy			Newly Diagnosed				T2DM, Poor Adherence				T2DM, Good Adherence			
		LTPA	Diet	LMP	LTPA	Diet	Meds	LMP	LTPA	Diet	Meds	LMP	LTPA	Diet	Meds	LMP
1.0%	E	A	DA	FT	DA	A	A	RT	DA	A	DA	RT	DA	A	A	RT
1.0%	U	DA	A	RT	DA	A	A	RT	DA	A	DA	RT	DA	A	A	RT
2.5%	E	DA	A	RT	DA	A	A	RT	DA	A	DA	RT	DA	A	A	RT
2.5%	U	DA	A	RT	DA	A	A	RT	DA	A	DA	RT	DA	A	A	RT
5.0%	E	DA	A	RT	DA	A	A	RT	DA	A	DA	RT	DA	A	A	RT
5.0%	U	DA	A	RT	DA	A	A	RT	DA	A	DA	RT	DA	A	A	RT
10.0%	E	DA	A	RT	DA	A	A	RT	DA	A	DA	RT	DA	A	A	RT
10.0%	U	DA	A	RT	DA	A	A	RT	DA	A	DA	RT	DA	A	A	RT
Age 85																
0.0%	E	A	DA	FT	A	DA	A	FT	A	DA	DA	FT	A	DA	A	FT
0.0%	U	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	A	RT
1.0%	E	A	DA	FT	DA	A	A	FT	DA	A	DA	FT	DA	A	A	FT
1.0%	U	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	A	RT
2.5%	E	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	A	RT
2.5%	U	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	A	RT
5.0%	E	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	A	RT
5.0%	U	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	A	RT
10.0%	E	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	A	RT
10.0%	U	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	A	RT

Table 48: Characteristics of Optimal Policy (Female; Asian-Indian; Bachelor's degree or above)—Parameter: Costs of Unhealthy Eating Habits Relative to Default Values																	
Value	**Employment Status**	**Healthy**			**Newly Diagnosed**				**T2DM, Poor Adherence**				**T2DM, Good Adherence**				
		LTPA	**Diet**	**LMP**	**LTPA**	**Diet**	**Meds**	**LMP**	**LTPA**	**Diet**	**Meds**	**LMP**	**LTPA**	**Diet**	**Meds**	**LMP**	
Age 25																	
0	E	DA	DA	FT													
0	U	DA	DA	FT													
0.5	E	DA	DA	FT													
0.5	U	DA	DA	FT													
1	E	DA	DA	FT													
1	U	DA	A	FT													
1.5	E	DA	A	FT													
1.5	U	DA	A	FT													
2	E	DA	A	FT													
2	U	DA	A	FT													
Age 35																	
0	E	A	DA	FT	A	DA	A	FT									
0	U	A	DA	FT	A	DA	A	FT									
0.5	E	A	DA	FT	A	DA	A	FT									
0.5	U	A	DA	FT	A	DA	A	FT									
1	E	A	DA	FT	A	DA	A	FT									
1	U	DA	A	FT	DA	A	A	FT									
1.5	E	DA	A	FT	DA	A	A	FT									
1.5	U	DA	A	FT	DA	A	A	FT									
2	E	DA	A	FT	DA	A	A	FT									
2	U	DA	A	FT	DA	A	A	FT									
Age 45																	
0	E	A	DA	FT	A	DA	A	FT	A	DA	A	FT	A	DA	A	FT	
0	U	A	DA	FT	A	DA	A	FT	A	DA	A	FT	A	DA	A	FT	
0.5	E	A	DA	FT	A	DA	A	FT	A	DA	A	FT	A	DA	A	FT	
0.5	U	A	DA	FT	A	DA	A	FT	A	DA	A	FT	A	DA	A	FT	
1	E	A	DA	FT	A	DA	A	FT	A	DA	DA	FT	DA	A	A	FT	
1	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT	

Table 48: Characteristics of Optimal Policy (Female; Asian-Indian; Bachelor's degree or above)—Parameter: Costs of Unhealthy Eating Habits Relative to Default Values

Value	Employment Status	Healthy			Newly Diagnosed				T2DM, Poor Adherence				T2DM, Good Adherence			
		LTPA	Diet	LMP	LTPA	Diet	Meds	LMP	LTPA	Diet	Meds	LMP	LTPA	Diet	Meds	LMP
1.5	E	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
1.5	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
2	E	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
2	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
Age 55																
0	E	A	DA	FT	A	DA	A	FT	A	DA	DA	FT	A	DA	A	FT
0	U	A	DA	FT	A	DA	A	FT	A	DA	A	FT	A	DA	A	FT
0.5	E	A	DA	FT	A	DA	A	FT	A	DA	DA	FT	A	DA	A	FT
0.5	U	A	DA	FT	A	DA	A	FT	A	DA	DA	FT	A	DA	A	FT
1	E	A	DA	FT	A	DA	A	FT	A	DA	DA	FT	A	DA	A	FT
1	U	DA	A	FT	DA	A	A	FT	DA	A	DA	FT	DA	A	A	FT
1.5	E	DA	A	FT	DA	A	A	FT	DA	A	DA	FT	DA	A	A	FT
1.5	U	DA	A	FT	DA	A	A	FT	DA	A	DA	FT	DA	A	A	FT
2	E	DA	A	FT	DA	A	A	FT	DA	A	DA	FT	DA	A	A	FT
2	U	DA	A	FT	DA	A	A	FT	DA	A	DA	FT	DA	A	A	FT
Age 65																
0	E	A	DA	FT	A	DA	A	FT	A	DA	A	RT	A	DA	A	FT
0	U	A	DA	RT	A	DA	A	RT	A	DA	A	RT	A	DA	A	RT
0.5	E	A	DA	FT	A	DA	A	FT	A	DA	A	FT	A	DA	A	FT
0.5	U	A	DA	RT	A	DA	A	RT	A	DA	A	RT	A	DA	A	RT
1	E	A	DA	FT	DA	A	A	FT	DA	A	A	RT	DA	A	A	FT
1	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
1.5	E	A	DA	FT	DA	A	A	FT	DA	A	A	RT	DA	A	A	FT
1.5	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
2	E	DA	A	FT	DA	A	A	FT	DA	A	A	RT	DA	A	A	FT
2	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
Age 75																
0	E	A	DA	RT	A	DA	A	RT	A	DA	A	RT	A	DA	A	RT
0	U	A	DA	RT	A	DA	A	RT	A	DA	A	RT	A	DA	A	RT

Table 48: Characteristics of Optimal Policy (Female; Asian-Indian; Bachelor's degree or above)—Parameter: Costs of Unhealthy Eating Habits Relative to Default Values

Value	Employment Status	Healthy			Newly Diagnosed				T2DM, Poor Adherence				T2DM, Good Adherence			
		LTPA	Diet	LMP	LTPA	Diet	Meds	LMP	LTPA	Diet	Meds	LMP	LTPA	Diet	Meds	LMP
0.5	E	A	DA	RT	A	DA	A	RT	A	DA	A	RT	A	DA	A	RT
0.5	U	A	DA	RT	A	DA	A	RT	A	DA	A	RT	A	DA	A	RT
1	E	DA	A	RT	DA	A	A	RT	DA	A	DA	RT	DA	A	A	RT
1	U	DA	A	RT	DA	A	A	RT	DA	A	DA	RT	DA	A	A	RT
1.5	E	DA	A	RT	DA	A	A	RT	DA	A	DA	RT	DA	A	A	RT
1.5	U	DA	A	RT	DA	A	A	RT	DA	A	DA	RT	DA	A	A	RT
2	E	DA	A	RT	DA	A	A	RT	DA	A	DA	RT	DA	A	A	RT
2	U	DA	A	RT	DA	A	A	RT	DA	A	DA	RT	DA	A	A	RT
Age 85																
0	E	A	DA	RT	A	DA	A	RT	A	DA	DA	RT	A	DA	A	RT
0	U	A	DA	RT	A	DA	A	RT	A	DA	DA	RT	A	DA	A	RT
0.5	E	A	DA	RT	A	DA	DA	RT	A	DA	DA	RT	A	DA	A	RT
0.5	U	A	DA	RT	A	DA	DA	RT	A	DA	DA	RT	A	DA	A	RT
1	E	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	A	RT
1	U	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	A	RT
1.5	E	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	A	RT
1.5	U	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	A	RT
2	E	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	A	RT
2	U	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	A	RT

Table 49: Characteristics of Optimal Policy (Female; Asian-Indian; Bachelor's degree or above)—Robustness Test: Negligible Risk of T2DM

Age	Empl. Status	Healthy			Newly Diagnosed				T2DM, Poor Adherence				T2DM, Good Adherence			
		LTPA	Diet	LMP	LTPA	Diet	Meds	LMP	LTPA	Diet	Meds	LMP	LTPA	Diet	Meds	LMP
Optimal policy																
25	E	DA	DA	FT												
25	U	DA	A	FT												
35	E	DA	DA	FT	A	DA	A	FT								
35	U	DA	A	FT	DA	A	A	FT								
45	E	DA	DA	FT	A	DA	A	FT	A	DA	DA	FT	DA	A	A	FT
45	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
55	E	DA	DA	FT	A	DA	A	FT	A	DA	DA	FT	A	DA	A	FT
55	U	DA	A	FT	DA	A	A	FT	DA	A	DA	FT	DA	A	A	FT
65	E	DA	DA	FT	DA	A	A	FT	DA	A	A	RT	DA	A	A	FT
65	U	DA	DA	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
75	E	DA	DA	RT	DA	A	A	RT	DA	A	DA	RT	DA	A	A	RT
75	U	DA	DA	RT	DA	A	A	RT	DA	A	DA	RT	DA	A	A	RT
85	E	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	A	RT
85	U	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	A	RT
Value function																
25	E	223,336			NA				NA				NA			
25	U	215,706			NA				NA				NA			
35	E	231,041			160,701				NA				NA			
35	U	220,838			152,333				NA				NA			
45	E	222,105			154,377				136,678				148,074			
45	U	211,879			146,174				130,095				141,104			
55	E	207,733			141,770				130,735				141,145			
55	U	195,106			131,791				122,131				132,405			
65	E	184,985			123,630				111,228				121,742			
65	U	182,987			123,276				111,228				121,312			
75	E	130,373			93,685				77,786				86,992			
75	U	130,373			93,685				77,786				86,992			
85	E	61,967			46,608				37,559				44,131			
85	U	61,967			46,608				37,559				44,131			

Table 50: Characteristics of Optimal Policy (Female; Asian-Indian; Bachelor's degree or above)—Robustness Test: Extreme Sleep Requirements

Age	Empl. Status	Healthy			Newly Diagnosed				T2DM, Poor Adherence				T2DM, Good Adherence			
		LTPA	Diet	LMP	LTPA	Diet	Meds	LMP	LTPA	Diet	Meds	LMP	LTPA	Diet	Meds	LMP
Optimal policy																
25	E	A	A	FT												
25	U	A	A	FT												
35	E	DA	DA	FT	DA	DA	DA	FT								
35	U	DA	DA	FT	DA	DA	DA	FT								
45	E	A	A	FT	DA	DA	DA	FT	A	A	DA	FT	A	A	DA	FT
45	U	A	A	FT	DA	DA	DA	FT	A	A	DA	FT	A	A	DA	FT
55	E	DA	DA	FT	DA	DA	DA	FT	A	A	DA	FT	A	A	DA	FT
55	U	DA	DA	FT	DA	DA	DA	FT	A	A	DA	FT	A	A	DA	FT
65	E	DA	DA	FT	DA	DA	DA	FT	DA	DA	DA	FT	DA	DA	DA	FT
65	U	DA	DA	FT	DA	DA	DA	FT	DA	DA	DA	FT	DA	DA	DA	FT
75	E	DA	DA	FT	DA	DA	DA	FT	DA	DA	DA	FT	DA	DA	DA	FT
75	U	DA	DA	FT	DA	DA	DA	FT	DA	DA	DA	FT	DA	DA	DA	FT
85	E	DA	DA	FT	DA	DA	DA	FT	A	A	DA	FT	DA	DA	DA	FT
85	U	DA	DA	FT	DA	DA	DA	FT	A	A	DA	FT	DA	DA	DA	FT

Age	Empl. Status	Healthy	Newly Diagnosed	T2DM, Poor Adherence	T2DM, Good Adherence
Value function					
25	E	-18,014,331	NA	NA	NA
25	U	-18,014,331	NA	NA	NA
35	E	-17,511,287	-17,459,503	NA	NA
35	U	-17,511,287	-17,459,503	NA	NA
45	E	-16,923,209	-16,246,244	NA	NA
45	U	-16,923,209	-16,246,244	NA	NA
55	E	-16,349,740	-15,587,325	-15,888,089	-15,949,585
55	U	-16,349,740	-15,587,325	-15,888,089	-15,949,585
65	E	-15,545,298	-15,012,151	-14,554,707	-14,713,197
65	U	-15,545,298	-15,012,151	-14,554,707	-14,713,197
75	E	-14,723,634	-13,941,081	-13,472,128	-13,595,030
75	U	-14,723,634	-13,941,081	-13,472,128	-13,595,030
85	E	-13,892,539	-12,929,022	-13,130,069	-13,393,052
85	U	-13,892,539	-12,929,022	-13,130,069	-13,393,052

Table 51: Characteristics of Optimal Policy (Female; Asian-Indian; Bachelor's degree or above)—Robustness Test: No Private Savings																
Age	**Empl. Status**	**Healthy**			**Newly Diagnosed**				**T2DM, Poor Adherence**				**T2DM, Good Adherence**			
		LTPA	**Diet**	**LMP**	**LTPA**	**Diet**	**Meds**	**LMP**	**LTPA**	**Diet**	**Meds**	**LMP**	**LTPA**	**Diet**	**Meds**	**LMP**
Optimal policy																
25	E	DA	DA	FT												
25	U	DA	A	FT												
35	E	A	DA	FT	A	DA	A	FT								
35	U	DA	A	FT	DA	A	A	FT								
45	E	A	DA	FT	A	DA	A	FT	A	DA	DA	FT	A	DA	A	FT
45	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
55	E	A	DA	FT	A	DA	A	FT	A	DA	DA	FT	A	DA	A	FT
55	U	DA	A	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
65	E	A	DA	FT	DA	A	A	FT	DA	A	A	FT	DA	A	A	FT
65	U	DA	A	RT	A	A	DA	RT	DA	A	A	RT	DA	A	A	RT
75	E	A	DA	FT	DA	A	A	FT	DA	A	A	RT	DA	A	A	RT
75	U	DA	A	RT	DA	A	A	RT	DA	A	A	RT	DA	A	A	RT
85	E	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	A	RT
85	U	DA	A	RT	DA	A	DA	RT	DA	A	DA	RT	DA	A	A	RT
Value function																
25	E	219,233			NA				NA				NA			
25	U	210,775			NA				NA				NA			
35	E	221,413			164,590				NA				NA			
35	U	210,571			155,320				NA				NA			
45	E	203,852			152,966				135,745				146,848			
45	U	192,998			143,793				127,957				138,833			
55	E	178,627			131,939				120,445				130,467			
55	U	165,246			120,810				110,769				120,880			
65	E	134,692			97,172				86,188				95,606			
65	U	126,443			91,142				83,375				91,002			
75	E	97,387			72,743				60,827				68,287			
75	U	97,280			72,608				60,827				68,287			
85	E	60,473			46,608				37,559				44,131			
85	U	60,473			46,608				37,559				44,131			

Table 52: Characteristics of Optimal Policy (Female; Asian-Indian; Bachelor's degree or above)—Robustness Test: Generous Basic Income																
Age	**Empl. Status**	**Healthy**			**Newly Diagnosed**				**T2DM, Poor Adherence**				**T2DM, Good Adherence**			
		LTPA	**Diet**	**LMP**	**LTPA**	**Diet**	**Meds**	**LMP**	**LTPA**	**Diet**	**Meds**	**LMP**	**LTPA**	**Diet**	**Meds**	**LMP**
Optimal policy																
25	E	DA	DA	PT												
25	U	DA	DA	FT												
35	E	A	DA	PT	A	DA	A	PT								
35	U	A	DA	FT	A	DA	A	FT								
45	E	A	DA	PT	A	DA	A	PT	A	DA	A	PT	A	DA	A	PT
45	U	A	DA	FT	A	DA	A	FT	A	DA	A	FT	A	DA	A	FT
55	E	A	DA	PT	A	DA	A	PT	A	DA	A	PT	A	DA	A	PT
55	U	A	DA	FT	A	DA	A	FT	A	DA	A	FT	A	DA	A	FT
65	E	A	DA	RT	A	DA	A	RT	A	DA	A	RT	A	DA	A	RT
65	U	A	DA	RT	A	DA	A	RT	A	DA	A	RT	A	DA	A	RT
75	E	A	DA	RT	A	DA	A	RT	A	DA	A	RT	A	DA	A	RT
75	U	A	DA	RT	A	DA	A	RT	A	DA	A	RT	A	DA	A	RT
85	E	A	DA	RT	A	DA	A	RT	A	DA	A	RT	A	DA	A	RT
85	U	A	DA	RT	A	DA	A	RT	A	DA	A	RT	A	DA	A	RT
Value function																
25	E	890,087			NA				NA				NA			
25	U	894,193			NA				NA				NA			
35	E	853,288			649,176				NA				NA			
35	U	857,425			652,498				NA				NA			
45	E	798,347			610,965				563,881				596,866			
45	U	802,481			614,283				566,712				600,058			
55	E	732,267			546,137				520,791				555,920			
55	U	737,119			550,019				524,062				559,660			
65	E	639,046			464,173				429,631				466,782			
65	U	639,046			464,173				429,631				466,782			
75	E	491,213			372,943				313,090				351,490			
75	U	491,213			372,943				313,090				351,490			
85	E	305,154			238,749				193,307				227,588			
85	U	305,154			238,749				193,307				227,588			

APPENDIX H: SIMULATION ANALYSIS DATA TABLES

Table 53: Detailed data table for simulation analysis results—**optimal policy versus full adherence**

Time	Population health				Indirect economic costs							
	Prevalence		Incidence		Absenteeism		Presenteeism		Premature mortality		Total losses	
	Opt.	Alt.	Opt.	Alt.	Opt.	Alt.	Opt.	Alt.	Opt.	Alt.	Opt.	Alt.
1	0.0%	0.0%	0.0	0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
2	0.4%	0.4%	3.5	3.5	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
3	0.7%	0.7%	3.7	3.7	$0.0	$0.0	$0.1	$0.1	$0.0	$0.0	$0.1	$0.1
4	1.2%	1.2%	4.3	4.3	$0.0	$0.0	$0.2	$0.2	$0.0	$0.0	$0.2	$0.2
5	1.6%	1.6%	4.3	4.3	$0.1	$0.1	$0.3	$0.3	$0.0	$0.0	$0.4	$0.4
6	2.0%	2.0%	4.3	4.3	$0.1	$0.1	$0.4	$0.4	$0.0	$0.0	$0.5	$0.5
7	2.4%	2.4%	4.3	4.3	$0.1	$0.1	$0.6	$0.6	$0.0	$0.0	$0.7	$0.7
8	2.9%	2.9%	5.5	5.5	$0.2	$0.2	$0.7	$0.7	$0.0	$0.0	$0.9	$0.9
9	3.4%	3.4%	4.3	4.3	$0.3	$0.2	$0.9	$0.9	$0.0	$0.0	$1.2	$1.1
10	3.8%	3.8%	4.4	4.4	$0.4	$0.4	$1.2	$1.2	$0.1	$0.1	$1.7	$1.7
11	4.3%	4.3%	5.2	5.2	$0.5	$0.5	$1.4	$1.4	$0.1	$0.1	$2.0	$2.0
12	4.7%	4.7%	4.8	4.8	$0.7	$0.6	$1.5	$1.5	$0.2	$0.2	$2.3	$2.3
13	5.2%	5.2%	4.8	4.8	$0.8	$0.7	$1.7	$1.7	$0.3	$0.3	$2.7	$2.7
14	5.6%	5.6%	4.7	4.7	$0.9	$0.8	$1.8	$1.8	$0.3	$0.3	$3.1	$3.0
15	6.1%	6.1%	5.0	5.0	$1.1	$1.0	$2.0	$2.0	$0.3	$0.3	$3.4	$3.3
16	6.5%	6.5%	4.0	4.0	$1.3	$1.1	$2.2	$2.2	$0.4	$0.4	$3.9	$3.7
17	6.9%	6.9%	4.3	4.3	$1.5	$1.3	$2.3	$2.3	$0.6	$0.6	$4.4	$4.2
18	7.3%	7.3%	4.4	4.4	$1.7	$1.5	$2.4	$2.4	$0.8	$0.8	$4.8	$4.6
19	7.6%	7.6%	3.9	3.9	$1.9	$1.7	$2.6	$2.5	$1.0	$1.0	$5.5	$5.1
20	7.9%	7.9%	3.6	3.6	$2.3	$2.0	$2.9	$2.9	$1.5	$1.4	$6.7	$6.3
21	9.5%	9.5%	17.7	17.7	$2.6	$2.2	$3.0	$3.0	$1.8	$1.7	$7.4	$6.9
22	11.0%	11.0%	16.4	16.4	$2.9	$2.5	$3.7	$3.6	$2.1	$2.0	$8.7	$8.2
23	12.5%	12.5%	18.0	18.0	$3.3	$2.9	$4.3	$4.2	$2.6	$2.5	$10.2	$9.6
24	14.1%	14.1%	19.5	19.5	$3.8	$3.3	$5.0	$4.9	$3.6	$3.5	$12.4	$11.7
25	15.7%	15.6%	18.4	18.4	$4.4	$3.7	$5.7	$5.6	$4.3	$4.2	$14.4	$13.5
26	17.0%	17.0%	16.7	16.7	$5.0	$4.2	$6.4	$6.3	$5.4	$5.3	$16.7	$15.8
27	18.2%	18.2%	15.3	15.3	$5.7	$4.8	$6.9	$6.8	$6.2	$6.2	$18.9	$17.7

Table 53: Detailed data table for simulation analysis results—**optimal policy versus full adherence**												
Time	**Population health**				**Indirect economic costs**							
	Prevalence		**Incidence**		**Absenteeism**		**Presenteeism**		**Premature mortality**		**Total losses**	
	Opt.	**Alt.**	**Opt.**	**Alt.**	**Opt.**	**Alt.**	**Opt.**	**Alt.**	**Opt.**	**Alt.**	**Opt.**	**Alt.**
28	19.4%	19.3%	15.9	15.9	$6.4	$5.3	$7.4	$7.3	$8.5	$8.4	$22.3	$21.0
29	20.7%	20.6%	17.2	17.2	$7.2	$5.9	$7.8	$7.7	$9.8	$9.7	$24.8	$23.3
30	21.9%	21.8%	16.9	16.9	$7.7	$6.3	$7.6	$7.5	$12.2	$12.1	$27.5	$25.9
31	23.2%	23.1%	18.4	18.4	$8.6	$6.9	$8.0	$7.9	$14.0	$13.9	$30.6	$28.7
32	24.4%	24.2%	15.8	15.8	$9.5	$7.5	$8.5	$8.3	$16.0	$15.9	$33.9	$31.7
33	25.6%	25.4%	17.2	17.2	$10.3	$8.1	$8.8	$8.6	$18.4	$18.2	$37.5	$35.0
34	26.6%	26.4%	16.3	16.3	$11.1	$8.6	$9.2	$9.0	$21.6	$21.4	$41.9	$39.0
35	27.7%	27.5%	17.4	17.4	$11.9	$9.1	$9.4	$9.2	$25.8	$25.5	$47.2	$43.8
36	28.7%	28.4%	16.3	16.3	$12.7	$9.5	$9.7	$9.4	$29.5	$29.0	$51.9	$48.0
37	29.7%	29.4%	15.6	15.6	$13.5	$10.0	$9.9	$9.6	$33.6	$33.0	$57.0	$52.6
38	30.5%	30.2%	15.0	15.0	$14.2	$10.2	$10.1	$9.8	$39.5	$38.9	$63.8	$58.9
39	31.4%	31.0%	15.8	15.8	$14.9	$10.5	$10.3	$9.9	$44.4	$43.7	$69.5	$64.1
40	32.2%	31.7%	16.2	16.2	$1.7	$1.0	$0.3	$0.1	$40.1	$40.4	$42.1	$41.5
41	33.7%	33.1%	26.1	26.1	$1.5	$1.0	$0.2	$0.1	$13.3	$13.6	$15.1	$14.7
42	35.0%	34.4%	26.1	26.1	$1.1	$0.2	$0.1	$0.0	$6.5	$6.4	$7.8	$6.6
43	36.2%	35.5%	23.8	23.8	$0.5	$0.0	$0.1	$0.0	$6.9	$6.9	$7.5	$6.9
44	37.4%	36.6%	24.8	24.8	$0.4	$0.0	$0.1	$0.0	$7.3	$7.2	$7.7	$7.2
45	38.6%	37.7%	27.1	27.1	$0.2	$0.0	$0.0	$0.0	$0.1	$0.2	$0.3	$0.2
46	39.9%	38.9%	28.5	28.5	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
47	40.8%	39.7%	25.5	25.5	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
48	41.9%	40.7%	26.8	26.8	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
49	42.7%	41.5%	26.9	26.9	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
50	43.6%	42.3%	26.2	26.2	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
51	44.4%	43.0%	25.5	25.5	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
52	45.3%	43.8%	26.0	26.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
53	45.6%	44.0%	23.1	23.1	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
54	46.1%	44.5%	25.9	25.9	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
55	46.7%	45.0%	25.1	25.1	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
56	47.1%	45.3%	26.4	26.4	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0

Table 53: Detailed data table for simulation analysis results—optimal policy versus full adherence												
Time	**Population health**				**Indirect economic costs**							
	Prevalence		**Incidence**		**Absenteeism**		**Presenteeism**		**Premature mortality**		**Total losses**	
	Opt.	**Alt.**	**Opt.**	**Alt.**	**Opt.**	**Alt.**	**Opt.**	**Alt.**	**Opt.**	**Alt.**	**Opt.**	**Alt.**
57	47.4%	45.6%	25.7	25.7	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
58	47.9%	46.2%	27.4	27.4	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
59	48.4%	46.5%	25.5	25.5	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
60	48.7%	46.8%	23.1	23.1	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
61	49.1%	47.1%	25.6	25.6	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
62	49.8%	47.8%	25.4	25.4	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
63	50.0%	48.0%	19.6	19.6	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
64	50.3%	48.3%	25.8	25.8	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
65	50.2%	48.3%	23.5	23.5	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
66	51.4%	49.5%	33.3	33.3	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
67	52.2%	50.4%	24.6	24.6	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
68	52.4%	50.6%	25.9	25.9	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
69	53.0%	51.2%	13.4	13.4	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
70	0.0%	0.0%	N/A	N/A	$0.0	$0.0	$0.0	$0.0	N/A	N/A	N/A	N/A

Table 54: Detailed data table for simulation analysis results—**optimal policy versus complete non-adherence**												
Time	**Population health**				**Indirect economic costs**							
	Prevalence		**Incidence**		**Absenteeism**		**Presenteeism**		**Premature mortality**		**Total losses**	
	Opt.	**Alt.**	**Opt.**	**Alt.**	**Opt.**	**Alt.**	**Opt.**	**Alt.**	**Opt.**	**Alt.**	**Opt.**	**Alt.**
1	0.0%	0.0%	0.0	0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
2	0.4%	4.1%	3.5	43.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
3	0.7%	8.3%	3.7	46.1	$0.0	$0.2	$0.1	$1.3	$0.0	$0.0	$0.1	$1.5
4	1.2%	12.3%	4.3	45.2	$0.0	$0.4	$0.2	$2.8	$0.0	$0.1	$0.2	$3.3
5	1.6%	15.9%	4.3	42.6	$0.1	$0.7	$0.3	$4.5	$0.0	$0.1	$0.4	$5.3
6	2.0%	19.3%	4.3	42.5	$0.1	$1.1	$0.4	$6.1	$0.0	$0.2	$0.5	$7.4
7	2.4%	22.6%	4.3	42.8	$0.1	$1.7	$0.6	$7.9	$0.0	$0.2	$0.7	$9.8
8	2.9%	26.3%	5.5	49.6	$0.2	$2.3	$0.7	$9.8	$0.0	$0.5	$0.9	$12.7
9	3.4%	29.4%	4.3	44.2	$0.3	$3.1	$0.9	$12.0	$0.0	$0.8	$1.2	$15.8
10	3.8%	32.6%	4.4	47.6	$0.4	$4.9	$1.2	$16.9	$0.1	$1.2	$1.7	$23.0
11	4.3%	35.5%	5.2	45.7	$0.5	$6.1	$1.4	$19.6	$0.1	$1.6	$2.0	$27.3
12	4.7%	38.3%	4.8	45.4	$0.7	$7.5	$1.5	$22.3	$0.2	$2.1	$2.3	$31.9
13	5.2%	40.8%	4.8	43.5	$0.8	$9.0	$1.7	$25.1	$0.3	$2.3	$2.7	$36.4
14	5.6%	43.2%	4.7	41.9	$0.9	$10.7	$1.8	$27.9	$0.3	$2.7	$3.1	$41.4
15	6.1%	45.6%	5.0	44.2	$1.1	$12.6	$2.0	$30.7	$0.3	$3.2	$3.4	$46.4
16	6.5%	47.8%	4.0	43.1	$1.3	$14.6	$2.2	$33.4	$0.4	$3.7	$3.9	$51.7
17	6.9%	50.0%	4.3	43.8	$1.5	$16.8	$2.3	$36.2	$0.6	$4.3	$4.4	$57.3
18	7.3%	51.9%	4.4	41.1	$1.7	$19.1	$2.4	$38.8	$0.8	$5.2	$4.8	$63.2
19	7.6%	53.5%	3.9	36.5	$1.9	$21.6	$2.6	$41.3	$1.0	$6.1	$5.5	$69.0
20	7.9%	55.3%	3.6	41.0	$2.3	$26.0	$2.9	$47.1	$1.5	$7.7	$6.7	$80.8
21	9.5%	59.5%	17.7	105.5	$2.6	$28.9	$3.0	$49.4	$1.8	$8.6	$7.4	$86.9
22	11.0%	63.2%	16.4	101.9	$2.9	$32.1	$3.7	$52.5	$2.1	$10.2	$8.7	$94.8
23	12.5%	66.3%	18.0	96.1	$3.3	$35.4	$4.3	$55.3	$2.6	$11.3	$10.2	$102.0
24	14.1%	69.1%	19.5	93.5	$3.8	$38.9	$5.0	$57.7	$3.6	$13.3	$12.4	$109.9
25	15.7%	71.9%	18.4	105.1	$4.4	$42.3	$5.7	$60.0	$4.3	$15.4	$14.4	$117.7
26	17.0%	74.0%	16.7	87.4	$5.0	$45.8	$6.4	$62.3	$5.4	$17.7	$16.7	$125.8
27	18.2%	76.2%	15.3	96.5	$5.7	$49.4	$6.9	$64.3	$6.2	$20.5	$18.9	$134.2
28	19.4%	78.1%	15.9	90.9	$6.4	$53.0	$7.4	$66.0	$8.5	$23.9	$22.3	$143.0
29	20.7%	79.8%	17.2	95.6	$7.2	$56.5	$7.8	$67.6	$9.8	$26.5	$24.8	$150.5

Table 54: Detailed data table for simulation analysis results—**optimal policy versus complete non-adherence**												
Time	**Population health**				**Indirect economic costs**							
	Prevalence		**Incidence**		**Absenteeism**		**Presenteeism**		**Premature mortality**		**Total losses**	
	Opt.	**Alt.**	**Opt.**	**Alt.**	**Opt.**	**Alt.**	**Opt.**	**Alt.**	**Opt.**	**Alt.**	**Opt.**	**Alt.**
30	21.9%	81.3%	16.9	89.2	$7.7	$58.4	$7.6	$65.8	$12.2	$30.9	$27.5	$155.2
31	23.2%	82.8%	18.4	94.5	$8.6	$61.3	$8.0	$66.8	$14.0	$34.7	$30.6	$162.8
32	24.4%	84.1%	15.8	91.2	$9.5	$64.0	$8.5	$67.7	$16.0	$39.0	$33.9	$170.7
33	25.6%	85.3%	17.2	97.8	$10.3	$66.2	$8.8	$68.2	$18.4	$43.5	$37.5	$178.0
34	26.6%	86.3%	16.3	90.6	$11.1	$67.8	$9.2	$68.5	$21.6	$49.4	$41.9	$185.7
35	27.7%	87.2%	17.4	86.0	$11.9	$68.9	$9.4	$68.3	$25.8	$55.9	$47.2	$193.1
36	28.7%	88.0%	16.3	82.5	$12.7	$69.8	$9.7	$68.0	$29.5	$61.8	$51.9	$199.6
37	29.7%	88.6%	15.6	76.4	$13.5	$70.1	$9.9	$67.3	$33.6	$69.4	$57.0	$206.7
38	30.5%	89.4%	15.0	92.2	$14.2	$69.8	$10.1	$66.3	$39.5	$79.2	$63.8	$215.3
39	31.4%	90.1%	15.8	98.7	$14.9	$69.1	$10.3	$65.4	$44.4	$87.0	$69.5	$221.5
40	32.2%	90.6%	16.2	84.7	$1.7	$12.5	$0.3	$6.9	$40.1	$87.9	$42.1	$107.3
41	33.7%	91.3%	26.1	98.3	$1.5	$9.1	$0.2	$4.3	$13.3	$34.0	$15.1	$47.4
42	35.0%	91.7%	26.1	79.4	$1.1	$6.8	$0.1	$2.2	$6.5	$17.8	$7.8	$26.9
43	36.2%	92.0%	23.8	73.2	$0.5	$3.4	$0.1	$1.1	$6.9	$20.7	$7.5	$25.2
44	37.4%	92.3%	24.8	80.9	$0.4	$0.3	$0.1	$0.0	$7.3	$24.5	$7.7	$24.9
45	38.6%	92.6%	27.1	86.3	$0.2	$0.1	$0.0	$0.0	$0.1	$0.2	$0.3	$0.4
46	39.9%	92.8%	28.5	76.4	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
47	40.8%	93.1%	25.5	83.2	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
48	41.9%	93.3%	26.8	65.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
49	42.7%	93.5%	26.9	93.1	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
50	43.6%	93.6%	26.2	79.4	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
51	44.4%	93.9%	25.5	99.8	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
52	45.3%	94.1%	26.0	87.2	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
53	45.6%	94.4%	23.1	92.1	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
54	46.1%	94.4%	25.9	78.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
55	46.7%	94.4%	25.1	74.4	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
56	47.1%	94.7%	26.4	117.9	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
57	47.4%	94.8%	25.7	90.1	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
58	47.9%	94.8%	27.4	82.9	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0

Table 54: Detailed data table for simulation analysis results—optimal policy versus complete non-adherence												
Time	Population health				Indirect economic costs							
	Prevalence		Incidence		Absenteeism		Presenteeism		Premature mortality		Total losses	
	Opt.	Alt.	Opt.	Alt.	Opt.	Alt.	Opt.	Alt.	Opt.	Alt.	Opt.	Alt.
59	48.4%	94.7%	25.5	71.8	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
60	48.7%	95.1%	23.1	158.6	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
61	49.1%	95.1%	25.6	87.3	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
62	49.8%	94.8%	25.4	44.6	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
63	50.0%	95.0%	19.6	97.8	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
64	50.3%	94.9%	25.8	62.5	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
65	50.2%	95.0%	23.5	92.3	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
66	51.4%	94.6%	33.3	0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
67	52.2%	94.5%	24.6	63.8	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
68	52.4%	94.6%	25.9	135.1	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
69	53.0%	94.0%	13.4	96.8	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
70	0.0%	0.0%	N/A	N/A	$0.0	$0.0	$0.0	$0.0	N/A	N/A	N/A	N/A

Table 55: Detailed data table for simulation analysis results—**optimal policy versus positive post-diagnosis behavioural shift**												
Time	**Population health**				**Indirect economic costs**							
	Prevalence		**Incidence**		**Absenteeism**		**Presenteeism**		**Premature mortality**		**Total losses**	
	Opt.	**Alt.**	**Opt.**	**Alt.**	**Opt.**	**Alt.**	**Opt.**	**Alt.**	**Opt.**	**Alt.**	**Opt.**	**Alt.**
1	0.0%	0.0%	0.0	0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
2	0.4%	4.1%	3.5	43.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
3	0.7%	8.3%	3.7	46.1	$0.0	$0.2	$0.1	$1.0	$0.0	$0.0	$0.1	$1.2
4	1.2%	12.3%	4.3	45.2	$0.0	$0.3	$0.2	$2.0	$0.0	$0.1	$0.2	$2.4
5	1.6%	15.9%	4.3	42.6	$0.1	$0.6	$0.3	$3.1	$0.0	$0.1	$0.4	$3.8
6	2.0%	19.3%	4.3	42.5	$0.1	$0.9	$0.4	$3.9	$0.0	$0.2	$0.5	$5.1
7	2.4%	22.6%	4.3	42.8	$0.1	$1.3	$0.6	$4.9	$0.0	$0.2	$0.7	$6.4
8	2.9%	26.3%	5.5	49.6	$0.2	$1.8	$0.7	$5.8	$0.0	$0.5	$0.9	$8.1
9	3.4%	29.4%	4.3	44.2	$0.3	$2.4	$0.9	$6.7	$0.0	$0.8	$1.2	$9.8
10	3.8%	32.6%	4.4	47.6	$0.4	$3.8	$1.2	$8.9	$0.1	$1.2	$1.7	$13.9
11	4.3%	35.5%	5.2	45.7	$0.5	$4.6	$1.4	$9.9	$0.1	$1.6	$2.0	$16.1
12	4.7%	38.3%	4.8	45.4	$0.7	$5.6	$1.5	$10.8	$0.2	$2.1	$2.3	$18.5
13	5.2%	40.8%	4.8	43.5	$0.8	$6.6	$1.7	$11.6	$0.3	$2.3	$2.7	$20.5
14	5.6%	43.2%	4.7	41.9	$0.9	$7.7	$1.8	$12.4	$0.3	$2.7	$3.1	$22.8
15	6.1%	45.6%	5.0	44.2	$1.1	$8.8	$2.0	$13.1	$0.3	$3.2	$3.4	$25.2
16	6.5%	47.8%	4.0	43.1	$1.3	$10.1	$2.2	$13.9	$0.4	$3.7	$3.9	$27.7
17	6.9%	50.0%	4.3	43.8	$1.5	$11.4	$2.3	$14.6	$0.6	$4.3	$4.4	$30.3
18	7.3%	51.9%	4.4	41.1	$1.7	$12.8	$2.4	$15.2	$0.8	$5.2	$4.8	$33.2
19	7.6%	53.6%	3.9	36.5	$1.9	$14.2	$2.6	$15.8	$1.0	$6.1	$5.5	$36.1
20	7.9%	55.4%	3.6	41.0	$2.3	$16.9	$2.9	$17.7	$1.5	$7.7	$6.7	$42.3
21	9.5%	59.6%	17.7	105.5	$2.6	$18.6	$3.0	$18.2	$1.8	$8.6	$7.4	$45.4
22	11.0%	63.3%	16.4	101.9	$2.9	$20.5	$3.7	$19.3	$2.1	$10.2	$8.7	$50.0
23	12.5%	66.5%	18.0	96.1	$3.3	$22.4	$4.3	$20.3	$2.6	$11.4	$10.2	$54.0
24	14.1%	69.3%	19.5	93.5	$3.8	$24.5	$5.0	$21.1	$3.6	$13.4	$12.4	$59.0
25	15.7%	72.2%	18.4	105.1	$4.4	$26.7	$5.7	$21.8	$4.3	$15.6	$14.4	$64.0
26	17.0%	74.4%	16.7	87.4	$5.0	$28.8	$6.4	$22.5	$5.4	$17.8	$16.7	$69.2
27	18.2%	76.6%	15.3	96.5	$5.7	$31.0	$6.9	$23.0	$6.2	$20.7	$18.9	$74.7
28	19.4%	78.4%	15.9	90.9	$6.4	$33.3	$7.4	$23.3	$8.5	$24.4	$22.3	$81.0
29	20.7%	80.2%	17.2	95.6	$7.2	$35.6	$7.8	$23.6	$9.8	$27.0	$24.8	$86.2

Table 55: Detailed data table for simulation analysis results—**optimal policy versus positive post-diagnosis behavioural shift**												
Time	**Population health**				**Indirect economic costs**							
	Prevalence		**Incidence**		**Absenteeism**		**Presenteeism**		**Premature mortality**		**Total losses**	
	Opt.	**Alt.**	**Opt.**	**Alt.**	**Opt.**	**Alt.**	**Opt.**	**Alt.**	**Opt.**	**Alt.**	**Opt.**	**Alt.**
30	21.9%	81.7%	16.9	89.2	$7.7	$36.9	$7.6	$22.1	$12.2	$31.7	$27.5	$90.7
31	23.2%	83.2%	18.4	94.5	$8.6	$38.9	$8.0	$22.2	$14.0	$35.4	$30.6	$96.5
32	24.4%	84.6%	15.8	91.2	$9.5	$40.9	$8.5	$22.2	$16.0	$39.8	$33.9	$102.9
33	25.6%	85.8%	17.2	97.8	$10.3	$42.6	$8.8	$22.3	$18.4	$44.6	$37.5	$109.5
34	26.6%	86.9%	16.3	90.6	$11.1	$44.0	$9.2	$22.2	$21.6	$50.8	$41.9	$117.0
35	27.7%	87.8%	17.4	86.0	$11.9	$45.3	$9.4	$22.1	$25.8	$57.6	$47.2	$124.9
36	28.7%	88.7%	16.3	82.5	$12.7	$46.4	$9.7	$21.8	$29.5	$64.1	$51.9	$132.3
37	29.7%	89.4%	15.6	76.4	$13.5	$47.2	$9.9	$21.6	$33.6	$72.1	$57.0	$141.0
38	30.5%	90.2%	15.0	92.2	$14.2	$47.7	$10.1	$21.3	$39.5	$82.7	$63.8	$151.6
39	31.4%	90.9%	15.8	98.7	$14.9	$48.0	$10.3	$21.0	$44.4	$91.3	$69.5	$160.4
40	32.2%	91.5%	16.2	84.7	$1.7	$8.3	$0.3	$1.0	$40.1	$85.3	$42.1	$94.5
41	33.7%	92.2%	26.1	98.3	$1.5	$7.4	$0.2	$0.7	$13.3	$31.3	$15.1	$39.3
42	35.0%	92.6%	26.1	79.4	$1.1	$4.8	$0.1	$0.3	$6.5	$15.6	$7.8	$20.7
43	36.2%	93.1%	23.8	73.2	$0.5	$2.4	$0.1	$0.3	$6.9	$18.1	$7.5	$20.8
44	37.4%	93.4%	24.8	80.9	$0.4	$2.0	$0.1	$0.2	$7.3	$21.0	$7.7	$23.2
45	38.6%	93.8%	27.1	86.3	$0.2	$0.7	$0.0	$0.1	$0.1	$0.2	$0.3	$1.0
46	39.9%	94.1%	28.5	76.4	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
47	40.8%	94.4%	25.5	83.2	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
48	41.9%	94.6%	26.8	65.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
49	42.7%	94.9%	26.9	93.1	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
50	43.6%	95.2%	26.2	79.4	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
51	44.4%	95.5%	25.5	99.8	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
52	45.3%	95.7%	26.0	87.2	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
53	45.6%	96.1%	23.1	92.1	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
54	46.1%	96.2%	25.9	78.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
55	46.7%	96.3%	25.1	74.4	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
56	47.1%	96.6%	26.4	117.9	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
57	47.4%	96.7%	25.7	90.1	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
58	47.9%	96.8%	27.4	82.9	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0

Table 55: Detailed data table for simulation analysis results—**optimal policy versus positive post-diagnosis behavioural shift**												
Time	**Population health**				**Indirect economic costs**							
	Prevalence		**Incidence**		**Absenteeism**		**Presenteeism**		**Premature mortality**		**Total losses**	
	Opt.	**Alt.**	**Opt.**	**Alt.**	**Opt.**	**Alt.**	**Opt.**	**Alt.**	**Opt.**	**Alt.**	**Opt.**	**Alt.**
59	48.4%	96.9%	25.5	71.8	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
60	48.7%	97.3%	23.1	158.6	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
61	49.1%	97.4%	25.6	87.3	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
62	49.8%	97.4%	25.4	44.6	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
63	50.0%	97.5%	19.6	97.8	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
64	50.3%	97.5%	25.8	62.5	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
65	50.2%	97.7%	23.5	92.3	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
66	51.4%	97.6%	33.3	0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
67	52.2%	97.6%	24.6	63.8	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
68	52.4%	97.7%	25.9	135.1	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
69	53.0%	97.7%	13.4	96.8	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
70	0.0%	0.0%	N/A	N/A	$0.0	$0.0	$0.0	$0.0	N/A	N/A	N/A	N/A