10-19-2020 9:30 AM

Understanding the Determinants of the Cost of Coronary Artery Bypass Graft Surgery

Hun Lee, *The University of Western Ontario*

Supervisor: John-Baptiste, Ava, *The University of Western Ontario*
Co-Supervisor: Lizotte, Daniel, *The University of Western Ontario*
A thesis submitted in partial fulfillment of the requirements for the Master of Science degree in Epidemiology and Biostatistics

Abstract

Introduction: The relationship between patient demographics, clinical factors, and cost of coronary artery bypass graft (CABG) is complex. Investigation of these relationships is important to aid clinical practice and inform reimbursement models. This thesis analyzes multiple different domains in order to understand the significant factors that impact the cost of CABG at the London Health Sciences Centre (LHSC).

Methods: Model selection, construction of nested descriptive models, exploration of mediation analysis of the impact of peri-operative factors and cost through length of stay, and construction of estimative models were performed.

Results: Several baseline characteristics, socio-demographics, peri-operative variables, and post-operative variables were found to be significant drivers of cost. Some of these include having dementia upon admission, experiencing major complications, and having longer length of stay.

Discussion: Through analysis of multiple domains, we begin to develop an understanding of the significant factors that impact the cost of CABG procedures at the LHSC.

Keywords

Coronary Artery Bypass Graft, Cost Analysis, Cost Prediction, Case-costing, Mediation Analysis

Summary for Lay Audience

At the London Health Sciences Centre (LHSC), around 850 coronary artery bypass graft (CABG) procedures are performed annually. CABG surgery involves grafting (sewing) vessels onto the arteries that supply blood to the heart to relieve narrowing of those arteries, a condition known as coronary artery disease. CABG surgery relieves coronary artery disease symptoms, which include pain, weakness and fatigue, and reduces the rate of death from coronary artery disease. Cardiac surgeons and hospital administrators are concerned the reimbursement for each CABG procedure provided by the Ontario Ministry of Health and Long-Term does not cover the actual cost of surgery, particularly for more complicated cases. Through analyses of hospital datasets, this thesis identified several significant drivers of cost. Some of these factors include having dementia upon admission to the hospital, experiencing major complications, and length of stay. We also performed analyses that showed that the relationship between these variables and costs are quite complex. We found that certain factors like major complications was not only associated with increased costs directly, but also increased the length of stay at the hospital. This increase in length of stay results in additional increased costs. We also showed that there were several variables that were very important in estimating the cost of CABG at the LHSC that were not accounted for by the models that are currently used to inform reimbursement of these procedures.

Co-Authorship Statement

Hun (Steven) Lee, Dr. Ava John-Baptiste, Dr. Dan Lizotte, Dr. Bob Kiaii, and Dr. Dave Nagpal contributed to the conception and design of the work. HSL was responsible for data analysis and interpretation. HSL drafted the article. All authors participated in critical revision of the article.

Acknowledgements

This past two years have been incredibly fulfilling in terms of both personal and professional growth. It is with the utmost pleasure to acknowledge several individuals that have helped me immensely throughout this journey.

First off, I would like to thank the members of my thesis committee: Dr. Ava John-Baptiste, Dr. Dan Lizotte, and Dr. Dave Nagpal. Each of these individuals have pushed me to the limits of my abilities and have always challenged me to think about problems from multiple different points of view. They help me find the delicate balance between exploring endless possibilities, and figuring out which of these possibilities is practical and feasible. These individuals have taught me how to reign in my breadth of educational experience and apply it to solve problems in a practical and accessible way. This invaluable skill will help me excel in my career as a researcher moving forward.

I would also like to thank several key mentors who gave me the utmost support and provided additional opportunities for me to learn and grow. These mentors include Dr. Matthew Meyer, Dr. Kelly Anderson, Dr. Neil Klar, and Dr. Yun-Hee Choi. Each of these individuals have provided invaluable advice and have provided me many opportunities to explore research that I would not have been exposed to otherwise. I would also like to thank the team at the Ivey International Centre for Health Innovation for always encouraging me throughout my time there. I must also acknowledge the Clinical Decision Support analysts for providing the data for this thesis.

To my colleagues, classmates, and dear friends, I am so incredibly grateful for the wonderful camaraderie we shared throughout these two years. All of the late night study sessions in Kresge, every discussion and debate, and every outing have been so important for me on this arduous journey. Thank you for always being open to listening to my (sometimes) unintelligible ramblings on.

Finally, I would like to thank my wonderful family for their incredible support in all of my endeavours. No matter how often or how far I fall down, they are always there to help me get back to my feet. Their encouragement always gives me the strength to dust myself off, and start moving forward again. Thank you for always believing in me, and providing me endless and unconditional support.

Table of Contents

List of Tables

List of Figures

List of Appendices

Chapter 1

1 Introduction

The Canadian Institute for Health Information (CIHI) estimated that the total health expenditure is expected to reach $254 billion or $7,068 per capita in 2019.[1] Overall, this will represent 14.6% of Canada's gross domestic product (GDP) in this year. However, there is concern that the current reimbursement strategy for healthcare providers in Ontario does not adequately account for the variability in resource consumption by patients. This is a particular concern in cardiac care. The primary goal of our study is to understand the significant determinants of cost for coronary artery bypass graft (CABG) surgery at the London Health Sciences Centre (LHSC). An understanding of these determinants would enable decision makers to allocate funds more efficiently and could increase overall quality of health services. Identification of the most significant determinants of cost for CABG surgery will help local hospital administrators to understand how to better allocate local funds, and clinicians to provide better quality of care and better value for money.

As many as 6473 coronary artery bypass graft (CABG) procedures were performed in hospitals across Ontario during the 2015/16 fiscal year.[2] Within the LHSC alone, 618 CABG procedures, excluding those performed alongside concomitant valve procedures, were performed in the 2019 fiscal year. Using anonymized patient-level data from the LHSC, we undertook an analysis to identify the most important factors behind the cost of CABG procedures. The factors we considered can be categorized in the following categories: patient socio-demographics, pre-operative clinical characteristics, socio-economic status variables, peri-operative factors, and post-operative factors

1.1 Objectives

The objectives are as follows:

1. Determine the most appropriate statistical model for regression analysis of total cost
2. Identify the factors that are significantly associated with the variation in total CABG costs with variables categorized into patient socio-demographics, pre-operative clinical characteristics, peri-operative factors, and post-operative factors.
3. Explore mediation of the impact of peri-operative factors on costs through length of stay.
4. Determine the estimative performance of models developed comparing models according to the aforementioned variable categorization

1.2 Thesis Layout

The chapters are laid out as follows: Chapter two provides background information on coronary artery disease, CABG and factors related to the cost of CABG, reimbursement of hospital costs, and analysis of hospital costs; Chapter three describes the various sources where the data were obtained, and the study methods; Chapter four describes the study results; and chapter five concludes the thesis with a discussion of the research findings.

Chapter 2

2 Literature Review

The following literature review first describes coronary artery disease (CAD) along with the various treatment options that are available to patients, in particular coronary artery bypass graft (CABG) surgery. A description of healthcare costs and reimbursement follows. The literature review continues with an overview of statistical considerations that need to be made when performing cost analysis and prediction. Finally, it finishes with an overview of socio-economic factors and their impact on general healthcare costs and costs of cardiac care.

2.1 Coronary Artery Disease

2.1.1 Definition

Coronary artery disease (CAD), also known as ischemic heart disease, is the one of the most common forms of heart disease.[3] The main cause of CAD is atherosclerosis (arteriosclerosis), which is characterized by the inflammation of the arterial walls resulting in formation of atherosclerotic plaques in the coronary artery which can impede blood flow to the heart.[4,5] There are many ways that CAD can manifest such as acute coronary syndrome (ACS), including angina pectoris, myocardial infarction (MI), and sudden cardiac death, as well as chronic coronary heart disease.[4]

2.1.2 Prevalence

Globally, heart disease is the leading cause of death with an estimated 8.9 million deaths due to heart disease in 2015.[6] In Canada, heart disease is the second leading cause of death despite major improvements in treatment, disease management, and public health interventions. In 2013, it was found that an estimated 2.4 million individuals (about 8% of the population) above the age of 20 years of age were living with diagnosed CAD.[6] The prevalence of diagnosed CAD among individuals above the age of 20 years has shown a slight decline over the last five years.

In Ontario, about 8.9% of the population or approximately 1 million individuals above 20 years were found to be living with CAD in 2015 which accounts for 54% of the prevalent cases of cardiovascular disease.[7]

2.1.3 Risk Factors

There are several factors associated with an increased risk of developing coronary artery disease. These risk factors include high blood pressure, high blood cholesterol, diabetes, obesity, unhealthy diet, smoking, and stress.[4,8,9] As such, the Canadian Cardiovascular Society (CCS) Guidelines recommends that a focused medical history and physical examination be obtained to appropriately document symptoms, cardiac risk factors, and signs of cardiovascular disease.[10] Furthermore, it is recommended that important comorbidities such as heart failure, cerebrovascular and peripheral vascular disease, and renal disease be fully documented.

2.1.4 Treatment of Coronary Artery Disease

Many treatment options are available for people who suffer from coronary artery disease. Treatment of CAD usually involves a combination of approaches that aim to improve quality of life, minimize symptoms, and improve prognosis by preventing cardiac complications (MI and death). According to the Canadian Cardiovascular Society clinical guidelines, once a diagnosis of CAD is made it is a priority to provide medical treatment.[11]

In addition to medical therapy, one may be treated by percutaneous coronary intervention (PCI), which is a minimally invasive procedure designed to improve blood flow to the heart, or revascularization by CABG. The choice between PCI and CABG can be quite complicated because many factors must be considered.[12]

2.1.4.1 Medical Therapy

Medical therapy for the treatment of CAD aims to minimize symptoms and increase quality of life. It is often the case that medical therapy can be implemented more readily than other treatment options.[11] Medical therapy of CAD consists of antiplatelet medication, angiotensin-converting enzyme (ACE) inhibitors or angiotensin receptor blockers, and anti-ischemic drugs such as β-blockers.[11,13] Other medications may be provided to patients to optimally manage risk factors or symptoms of heart failure or MI. Guidelines recommend that implementation and optimization of a medical regimen should be achieved within the first 12-16 weeks after initial diagnosis of CAD.[11] During this time, it is recommended that adequacy of symptom control and quality of life should be assessed before consideration of revascularization.

2.1.4.2 Percutaneous Coronary Intervention

Percutaneous coronary intervention (PCI) involves the insertion of a catheter tube in order to open coronary arteries that are narrowed or blocked by the buildup of plaque along the arterial walls.[14] Typically, a cardiac stent is placed within the blocked artery in order to improve blood flow. The evolution of PCI technology occurred in waves beginning with the advent of the percutaneous intervention using fixed wire systems that were eventually replaced by movable wire systems.[14] The goal of these systems was to provide a less invasive alternative intervention to CABG, but these initial technologies had unintended consequences, such as acute or threatened closure, that demanded surgical revascularization or more intensive medical therapy.[14] However, technological and procedural advancements, such as the advent of drug-eluting stents, have made PCI much safer and have reduced the need for emergency CABG after initial PCI.[4]

There has been mixed evidence regarding overall effectiveness of PCI for patients with stable CAD and several studies have attempted to elucidate this. One such study compared revascularization (either through CABG or PCI) to medical therapy only in a prospective cohort study and found that revascularization improved outcomes and decreased risk of mortality.[15] Other studies, however, found that when PCI plus medical therapy was compared directly to medical therapy only it was found that there was no statistically significant difference in MI outcomes or mortality.[16,17]

2.1.4.3 Coronary Artery Bypass Graft

Coronary artery bypass graft surgery is another treatment option that is available for patients with CAD. CABG involves harvesting of a healthy blood vessel from the patient, which is then used to bypass the blocked area of the afflicted vessel. There sometimes may be a need for multiple bypasses during the same revascularization procedure. Historically, the saphenous vein was used for the revascularization but advances in surgical technology have led to the use of other conduit vessels such as the radial artery.[18,19]

The mortality rate for a primary CABG revascularization is expected to be 1.5%.[19] However, this rate is influenced by individual patient characteristics. These risk factors include the severity of left ventricular dysfunction, number of occluded vessels, age, presence of diabetes mellitus, gender, peripheral vascular disease, renal insufficiency, and pulmonary disease.[19] Patients that are older than 70 years of age have operative mortality two to three times that of the average CABG patient.[20,21]

Several papers have been published regarding the efficacy of CABG vs PCI, most of which indicated that CABG is preferred to PCI in patients with comorbid conditions and severe CAD. The Future Revascularization Evaluation in Patients With Diabetes Mellitus: Optimal Management of Multivessel Disease (FREEDOM) trial compared multivessel PCI to CABG in diabetic patients on optimal medical therapy.[22] This trial showed that CABG was superior to PCI and significantly reduced rates of mortality and post-procedure MI. However, there was a higher risk of stroke. CABG patients from the FREEDOM trial were also found to have slightly better quality of life than those who underwent PCI, though this benefit was very slight.[23]

The Synergy Between Percutaneous Coronary Intervention With TAXUS and Cardiac Surgery (SYNTAX) trial compared PCI with a paclitaxel-eluting stent vs CABG for patients with 3-vessel or left main CAD.[24] Similar to the FREEDOM trial, CABG patients had lower all-cause mortality and post-procedure MI. CABG patients in this trial, however, were found to have fewer stroke complications. These patients also had decreased need for revascularization. Overall, the evidence indicates CABG is superior to PCI in patients with severe CAD. However, it is not so evident that this is the case for the average CAD patient.[25] Observational studies suggest that CABG patients may have improved long-term survival compared with those who undergo PCI, but these results are difficult to clearly interpret due to confounding factors.[12,26]

2.1.5 Cost of Coronary Artery Bypass Graft

In Ontario, the volume of CABG surgeries being performed has been declining over the past 15-20 years.[27] There has been a significant shift to PCI that has caused the average CABG patient in Ontario to be older with more comorbidities. As a result, the average CABG case is more complex than that of 15-20 years ago. This in turn has several implications on the cost of CABG procedures.

Several factors contribute to increased CABG costs. Body mass index has been shown to have a complex relationship with CABG costs for patients in Ontario, Canada.[28] Patients who were underweight, morbidly obese, and normal weight all had much higher per patient costs than obese or overweight patients. However, overweight or obese patients contribute the most to total annual costs to the healthcare system as a group – likely due to the high proportion of CABG patients falling into these categories.[28] Frailty is another factor that has been shown to significantly increase costs of cardiac surgery.[29] Other factors that influence the cost of CABG surgery include several risk factors that affect CABG outcomes such as presence of diabetes, peripheral vascular disease, and age.[30,31] These risk factors have also been shown to be risk factors for delayed extubation.[32] Early extubation and fast track cardiac anesthsia has been found to be associated with decreased intensive care unit (ICU) and hospital length of stay resulting in reduced total CABG costs.[32–35] Whether the procedure was performed with the use of a heart-lung machine or not also has several cost implications. Thus, there is a wide debate surrounding the cost-effectiveness of so-called on-pump versus off-pump surgery.

2.1.7.1 On-pump vs Off-pump Coronary Artery Bypass Graft

The Coronary Artery Bypass Graft Off or On Pump Revascularization Study (CORONARY) trial was a trial that set out to assess which method of CABG was best. After 1 year, the average total cost per patient was found to be comparable between on-pump and off-pump procedures.[36] They had also found that there was no observed difference in the rate of a primary composite outcome of death, stroke, myocardial infarction, or renal failure.[37] Similar results were found in the MASS III trial which also sought to determine whether on-pump CABG was more cost-effective than off-pump CABG.[38]

2.2 Reimbursement and Case-costing of Hospital Costs

2.2.1 Hospital Funding in Ontario

Healthcare expenditures account for about 15% of Canada's GDP. Hospitals account for approximately 30% of total healthcare expenditures representing the largest single component of expenditures (around $45 billion).[39] As such, hospitals represent a substantial burden on provincial healthcare budgets. Prior to the 2012 health system funding reform (HSFR), hospitals in Ontario were funded using a global funding strategy.[40] In this funding regime, a fixed (global) amount of funding was distributed to hospitals based upon case mix, historical budgets, inflation rate, capital investment decisions, negotiation, institution size, and politics. This type of funding strategy is effective at limiting expenditure growth although hospitals have responded to restricted budgets by limiting admissions, which has led to a lengthening in wait times for surgical procedures.[39] There have also been concerns that having a global funding strategy has led to inequitable allocation of funds. Global funding also does not take into adequate consideration the complexity of services provided, type of institution, or any quality measures.[39]

In order to account for variability in hospital costs, governments internationally have begun to adopt funding strategies based upon the type and volume of services provided. This activity-based funding (ABF) or case-based funding, is more complex than global funding and funds hospitals based on the complexity of patients served and the volume of services provided.[39]

In 2012, Ontario underwent the HSFR which shifted the hospital funding strategy from a global funding regime to an ABF strategy known as patient-based funding (PBF).[40] PBF was implemented as a way to provide a clearer link between hospital funding and patient care. Under this new funding regime, large hospitals receive funding through three different funding models. The breakdown of funding is as follows: 40% from the health-based allocation model (HBAM), 30% from quality-based procedures (QBP), and the remaining 30% from a global budget based upon the previous year. The two main components of PBF, HBAM and QBP, are described in detail below.

2.2.2 Quality-Based Procedures

Global funding strategies are not able to appropriately account for the complexity of services provided nor are they able to completely capture the true costs of providing health care services.[39] Global funding strategies also do not properly incentivize hospitals to shorten lengths of stay and improve the cost-effectiveness of services provided. As part of the HSFR, the Ontario government implemented a QBP funding strategy.

QBP's are specific sets of services that have been identified as having the most potential to improve quality outcomes and reduce costs. Some QBP's are hip fracture and pneumonia introduced in fiscal year 2015 and breast cancer surgery introduce in fiscal year 2017.[41] QBP's are identified based upon an evidence-based framework which assesses patient services according to five key perspectives: practice variation, availability of evidence, feasibility for change, cost impact, and impact of transformation.[42] The Ministry of Health and Long-term Care (MOHLTC) adopted a multi-year implementation strategy, introducing new QBP's each year. For each cluster of procedures, clinical handbooks are created to outline best practices and suggest implementation pathways that ensure consistent delivery of care.[43] Funding for these QBP's are provided using a standard rate (or price) adjusted for the types of patients they serve. Essentially, procedures that are a part of a QBP group are funded based on volume.

2.2.3 Health Based Allocation Model (HBAM) and HBAM Inpatient Grouper Weights

The health-based allocation model, or HBAM, is another way in which the Ontario government has tried to appropriately capture the complexity and nuance surrounding funding for patient care. HBAM estimates the expected weighted cases, accounting for the fact that some hospitals treat more high-resource patients than others, and similarly expected costs.

To determine a given hospital's expected unit cost, a provincial average cost is measured for each type of care (e.g. Acute Inpatient and Day Surgery). Then, adjustments are made to reflect the variability in cost of care between hospitals. Factors that are adjusted for include level of academic activity and teaching, geography, degree of specialization, hospital type, and hospital size.

Once the expected expenses are determined for a hospital, the percentage of HBAM expected share is calculated by dividing that hospitals expected expenses by the provincial total expected expenses. This percentage share is then multiplied by the total available funding envelope for the province to derive each hospital's funding for a given type of care. It should be noted that the HBAM methodology uses data that is two years old in order to estimate expected weighted cases and costs. For example, the data used for estimation of expected cases and costs for fiscal year 2018/2019 is from fiscal year 2016/2017.

HBAM Inpatient Grouper (HIG) weights are used to determine the relative resource needs of any given patient in a hospital. These weights are used to determine the expected weighted cases at a given hospital.[44] The HIG weight for a given case is determined using the Case Mix Group (CMG+) grouping methodology, designed to group together patients with similar clinical characteristics and resource-utilization, along with additional clinical information. In fact, the HIG group is the same as the CMG+ group in most cases (83% of cases).[45] The remaining cases are assigned to one of 40 HIG groups based upon diagnosis, presence/absence of comorbid cardiac conditions among cardiac CMG+ groups, presence of comorbidities in obstetric cases using a comorbidity level (CL).[45] There is a separate intervention-driven group for bone marrow/stem cell transplant cases.

Once a case is assigned to a specific HIG or CMG+ group, adjustments are made based upon seven factors to account for the variation in resource consumption and length of stay among patients that pertain to any given HIG or CMG+ grouping.[45] These seven factors are: age, flagged intervention (FI), intervention event (IE), out-of-hospital (OOH) intervention, special care unit (SCU), discharged to home care, and maternal age ≥ 40.

These factors are then used to calculate the weight and expected length of stay (ELOS) for each case.[45] As mentioned previously, several factors contribute to the increase in CABG costs such as frailty and other risk factors that affect CABG outcomes.[29–31] There is concern that the HIG methodology may not appropriately account for these factors.

2.2.4 Case Costing of Hospital Costs

Case costing, also known as patient costing, is an activity-based costing model that tracks and costs delivery of healthcare services to patients by service date.[46] Hospital case-costs can be broken up into four broad categories: variable direct, variable indirect, fixed direct, and fixed indirect costs. These costs categories correspond to the different service types that are provided to patients. Variable costs are proportionate with the amount of care that was provided whereas fixed costs are independent of the amount of care provided. The case cost data are obtained from designated hospitals and used by the Canadian Institute for Health Information (CIHI) to support development of the reimbursement formulas described above, and to assist ministries of health in planning for and reimbursement of hospital costs.[46] LHSC is one of the Ontario hospitals that conducts case costing. Case cost data provide the most accurate picture of the true cost of hospital care.

Variable direct costs pertain to various expenditures that are directly proportionate to the amount of care that was provided. These costs include compensation of medical personnel involved in providing care, materials and supplies used throughout delivery of the services provided, medications provided throughout the hospital stay, and services that may have been contracted out.

Fixed direct costs pertain to costs of labour not related to the support of direct patient care. This includes management and support salaries, and salaried physicians. Fixed costs also included sundry expenses and hospital operation costs, such as building amortization, maintenance costs, and equipment leases/rental.

Variable indirect and fixed indirect costs pertain to the operating expenses allocated from transient functional centres such as administration, finance, human resources. A portion of the cost of a patient's stay can be attributed to these costs. It should be noted that the variable indirect costs at the LHSC are combined under fixed indirect.

2.3 Regression Analysis of Hospital Costs

2.3.1 Ordinary Least Squares Regression

Typically, ordinary least squares (OLS) regression is used to analyze outcomes that are continuous. A set of assumptions must be met in order to appropriately use OLS regression for analysis. In particular, variance of residuals must be independent of predictors (i.e. homoscedastic) and the residuals must be normally distributed.[47]

Cost data are not suitable for analysis using OLS regression. Cost data are typically characterized by nonnegative measurements and positive skew.[48] Additionally, the data are often heteroscedastic, that is the variance in regression cost estimates depends on the estimated value, rather than being constant across the range of costs.[49] There are many ways in which researchers have tried to account for these violations of standard ordinary least-squares (OLS) assumptions.

2.3.1 Linear Regression on Transformed Costs

Historically, linear regression was commonly used to analyze costs. An example of this can be seen in a paper published by Naglie et al in 1999.[30] Using multiple linear regression analysis, they estimated the effect of age on CABG costs adjusting for several covariates such as sex, presence of diabetes and other comorbid conditions, and complications. They found that CABG costs were much higher in older patients, especially among more complex cases. However, the cost estimates presented in this paper may be heavily biased and imprecise due to the use of multiple linear regression.

In order to perform simple linear regression, OLS assumptions need to be met. In particular, the residuals must be normally distributed and homoscedastic. Costs, however, severely violate these assumptions.[49] These violations may lead to results that are biased. To account for violations of assumptions underlying OLS, researchers have historically relied on performing linear regression on logarithmic or other Box-Cox transformed costs.[50] The analyses are no longer concerned with the mean costs, but with mean costs on a transformed scale. Therefore, in order to derive proper inferences about mean costs, one must perform a retransformation from the estimation scale (logarithmic or otherwise) to the scale of interest.[49,50] However, these transformations introduce complexity with regard to the analyses. Additionally, the estimate has been shown to be biased in the presence of heteroscedasticity on the log-scale.[48] To account for this bias, ‘smearing’ estimates have been developed such as the Duan smearing estimate.[51] However, these estimators are only useful in the presence of heteroscedasticity on the log-scale.[51,52]

2.3.2 Generalized Linear Models

One way to avoid the problems with retransformation, is the use of generalized linear models (GLM). GLMs are characterized by a distribution function for the conditional outcome, and a link function, which relates the conditional outcome to the specified set of covariates. The distribution function focuses on describing the conditional outcome whereas the link function describes the scale on which covariates in the model relate to the outcome.[49] The retransformation problems encountered when using linear regression are avoided with GLM's because the link function performs transformation on the mean outcome instead of performing the transformation first before calculation of the mean.[50] Furthermore, GLM's allow for heteroscedasticity in the non-transformed outcome. The difficulty with using GLM's comes from the need to specify an appropriate distribution function that fully describes the distribution of the residuals of the outcome variable. Considerations must be made with regard to the shape of the distribution and the relationship between the variance and the mean. Close assessment of this relationship provides guidance as to which distribution function may be most appropriate. However, there is little theoretical guidance as to which link function is most appropriate – though the log link has become ubiquitous.[53] One approach that has been suggested is to use a series of diagnostic tests to assess a set of candidate link and variance functions such as the modified Park test.[54] Information criteria such as the Akaike Information Criteria (AIC) have been shown to be useful in identifying the best fitting variance and link functions, though the usefulness of AIC in the latter case is limited to situations when there are several predictors.[49] However, it is often the case that even if these tests detect problems they do not provide any guidance on how to appropriately correct those problems. Despite these difficulties, GLM's are an attractive regression method for analyzing healthcare cost data by providing a flexible method that accounts for violations of OLS assumptions.[49]

There is extensive literature that demonstrates the usefulness of GLM methods for the analysis of healthcare costs. Barber et al illustrated this using data from the UK700 trial, a large multi-centre randomized trial to investigate the cost-effectiveness of intensive compared with standard case management in community care for patients with mental illness.[49] GLM's have also been shown to be useful in analyzing the costs of CABG surgery. In their review of regression methodologies for analysing cost of CABG surgeries Austin et al compared several specifications of GLM's with other regression methods including linear regression on log-transformed cost, and Cox proportional hazard regression.[31] Specifically, they compared using negative binomial, gamma, and Poisson distribution functions each with log-link. They found that negative binomial and gamma GLM identified the same covariates as statistically significant whereas discrepancies were found with other regression methods. Linear with log-transformed cost and Poisson GLM only disagreed with negative binomial and gamma GLM's in only one instance. Additionally, they found that negative binomial and gamma GLM's provided similar coefficient estimates in the descriptive models whereas the estimates in the Poisson GLM tended to be larger in magnitude. Conversely, the estimates from linear regression on log-transformed costs were found to be smaller in magnitude than estimates from negative binomial and gamma GLM's. It should be noted that the direction of the effects of covariates on CABG costs were the same for all regression methods.[31] When comparing each regression method for prediction of costs, Austin et al fond that Poisson

GLM had the lowest mean squared prediction error (MSPE) while linear regression with log-transformed costs had the lowest bias. A large limitation in this study is that no attempt was made to determine which regression method best fit the data for the descriptive model. Overall, GLM's are frequently used in the econometrics literature for the analysis of healthcare costs.[31]

2.4 Socioeconomic Status and Costs

Universal health care systems are designed with the goal of providing access to health services based on patient need. In Canada, medically necessary are paid for through provincial health insurance, with no access fees. Despite universal access to hospital and physician services, there is evidence that those of lower socioeconomic status may be less likely to receive or utilize specific services than those of higher status.[55,56] This inequity of access and utilization has been shown to be associated with overall higher health expenditure.[57,58] In the case of cardiac care, lower socioeconomic status is associated with lower access to invasive cardiac procedures.[59–61] Lower socioeconomic status is also associated with higher rates of mortality and worse cardiac outcomes.[62–65] However, there is very little literature regarding the impact that socioeconomic status might have on healthcare costs in cardiac care. One study assessed the importance of using socioeconomic status as a predictor of cardiovascular outcome and costs among women with suspected myocardial ischemia. This study used data from the Women's Ischemia Syndrome Evaluation (WISE) study and found that women of lower socioeconomic status were predicted to have higher rates of cardiovascular mortality and higher hospitalization and drug costs.[65]

2.4.1 Ontario Marginalization Index

The Ontario marginalization index (ON-Marg), developed for Public Health Ontario in collaboration with the Centre for Urban Health Solutions at St. Michael's Hospital, is an area-based measure of socioeconomic status that differentiates among Ontario geographic areas to aid in understanding inequalities.[66] The index is based on data from the Canadian Census. The ON-Marg is similar to the Canadian Marginalization Index (CAN-Marg), but uses Ontario-specific data. Guided by previous research in area-based deprivation indices, researchers performed a principal component factor analysis of 42 measures selected from the 2001 Canadian Census of Population and this yielded four factors that corresponded to 18 census tract measures.[66,67] The four factors include residential instability, material deprivation, dependency, and ethnic concentration. Factor analysis of the aforementioned census tract measures yields an index score for each of the four marginalization dimensions, based on data from the most recent Canadian census. Each index score is such that higher scores correspond to higher marginalization.

Residential instability refers to the concentration of people who experience family or housing instability within a given area. This measure relates to a neighbourhood's quality, cohesiveness, and supports.[66] The indicators that contribute to this score are the proportion of the population that live alone, proportion of the population who are not youth (between the ages of 5 and 15), the average number of persons per dwelling, the proportion of dwellings that are apartment buildings, the proportion of the population who are single/divorced/widowed, the proportion of dwellings that are not owned, and the proportion of the population who moved during the past 5 years.

Material deprivation is a measure of poverty and is associated with the inability of individuals and communities to access and attain basic material needs.[66] This measure is comprised of six indicators: the proportion of the population aged 20 or older without a high school diploma, the proportion of families who are lone parent families, the proportion of total income from government transfer payments for those aged 15 or older, the proportion of the population aged 15 years or older who are unemployed, and the proportion of the population considered low-income.[66,67] Material deprivation captures an area's income, housing quality, and educational attainment characteristics.

Dependency is also related to income. This measure relates to the number of people who do not have income from employment.[66] The dependency score is calculated from the proportion of the population who are aged 65 and older, a dependency ratio (calculated by dividing the total population who are 0 to 14 years of age and 65 or older by the total population between 15 and 64 years), and the proportion of the population not participating in the labour force who are aged 15 or older.[66,67]

Ethnic concentration captures the concentration of people who are recent immigrants and/or those belonging to a visible minority group. The indicators used to create the ethnic concentration score are the proportion of the population who are recent immigrants (those who arrived in the past 5 years) and the proportion of the population who self-identify as a visible minority.[66,67] The ON-Marg provides index scores for several different levels of aggregation including dissemination area, census tract, and public health unit.

The ON-Marg measures are often used to assess the impact of socioeconomic factors on indicators of health and has even been used to study how sociodemographic factors affect costs. In a population-based, retrospective cohort study, Thavorn et al. found that multimorbidity was associated with increased healthcare costs.[68] This association was found to be much greater for those who lived in areas with higher levels of marginalisation.

To our knowledge, there is no literature demonstrating the use of the ON-Marg in relation to cardiac costs. However, there is some literature that show the impact of marginalization on cardiac outcomes and risk factors.[69–71] One such study found that those living in areas of higher material deprivation were at higher risk for cardiovascular disease due to higher rates of smoking and lower physical activity.[71] Another study found that multimorbidity was significantly higher in the most deprived areas which will influence healthcare costs.[68,72]

2.5 Summary

The literature presented here provides background information to support the investigation of the impact of patient characteristics, socio-demographics, and clinical factors on CABG costs at the LHSC. Additionally, the literature highlights the funding model currently used to inform reimbursement in Ontario and concern that the funding models may not appropriately account for variation in CABG costs.

Chapter 3

3 Methods

Our overall goal was to use case cost data to determine the causes of variation in the cost of CABG procedure for patients treated at the LHSC. This information can aid hospital clinicians and administrators in understanding the factors that influence cost and identifying discrepancies between the significant cost drivers and the factors that are considered in existing funding models. This study was approved by the Office of Human Research Ethics at the University of Western Ontario.

To achieve this overall goal, we first tested a range of statistical models and chose the best fitting models for regression analysis of cost. Using this best fitting model, we performed descriptive regression analyses to identify the importance of groups of variables, including patient characteristics, sociodemographic variables, peri-operative characteristics, and post-operative characteristics. We then explored how length of stay may mediate the relationship between peri-operative factors and total cost. The following chapter describes the methods used for each of these analyses.

3.1 Cohort Selection

The study cohort contains all patients who underwent an elective CABG procedure from April 1st, 2014 to March 31st, 2019. This does not include patients who underwent concomitant valve procedure (including trans-catheter aortic valve implantation (TAVI), mitral valve repair, and tricuspid valve repair) or any patients who underwent two CABG procedures within the same hospital visit. Of a total 3,335 cases, 94 were excluded due to missing data. The data that were missing were due to missing forward sortation area or missing baseline characteristic information. Thus, a total 3,241 cases were used in the complete case analyses. There was one patient who had two CABG procedures during the study period.

3.2 Data Source and Data Linkage

Data were derived from several different clinical and administrative databases. These databases include the Canadian Institute of Health Information (CIHI) discharge abstract database (DAD), SurgiNet database, Canadian Patient Cost Database (i.e. case cost data), Cerner Electronic Health Record, and the CorHealth registry.

The DAD, maintained by CIHI, was originally developed in 1963 and captures administrative, clinical, and demographic information, including deaths, sign-outs, and transfers, for hospital inpatients and day surgery.[73] The DAD was mainly used to determine the study cohort and to identify pre-patient characteristics such as presence of diabetes or other comorbidities upon admission, any complications during patient stay, use of special care units, and discharge disposition. The SurgiNet database contains information regarding each patients' pre-admission clinical visit. This database was used to check for history of co-morbidities.

The Canadian Patient Cost Database, also maintained by CIHI, contains all case cost information for each patient stay.[46] Case costing refers to the activity-based costing model that is used to track and cost the services that are delivered to each patient.[46] The variables extracted from this database include variable direct labour, variable direct other, variable direct labour plus – which is the sum of variable direct labour and direct other, variable direct material goods and service (GS), variable direct material patient specific supplies (PSS), variable direct material – which is the sum of the variable direct material

GS and variable direct material PSS, fixed direct labour, fixed direct building, equipment, and grounds (BEG), fixed direct other, fixed direct – which is the sum of all fixed direct variables, fixed indirect costs, and total costs.

The Cerner Electronic Health Record is maintained by the LHSC and contains patient information related to their clinical presentation and inpatient stay. The variables obtained from this database are: patient height and weight, procedure duration, blood product transfusion (blood, plasma, and/or platelets), and albumin transfusion.

The CorHealth registry, maintained by CorHealth, provides clinically relevant comorbidity information and cardiac specific data. The variables extracted from this database include Canadian Cardiovascular Society (CCS) classification of Angina Pectoris, and New York Heart Association (NYHA) classification of heart failure. These databases were linked by the Clinical Decision Support team at the LHSC using a unique, anonymized encounter number.

Socio-economic status variables were obtained from the Ontario Marginalization Index that was created by Public Health Ontario in collaboration with the Centre for Urban Health Solutions at St. Michael's Hospital.[66] The dissemination area-level ON-Marg indices were aggregated to the forward sortation area (FSA) level using the Postal Code Conversion File. This file, created by Statistics Canada, contained information about which dissemination areas map to which FSAs.[74] The FSA-level ON-Marg indices were then assigned to each patient according to the FSA in which they resided. The FSA, delineated by the first three characters of the patient postal code, was taken from the Cerner electronic health record. A full list of variables can be found in the data dictionary (Appendix A).

3.3 Measures

The variables available in the full dataset fall into the following categories: patient costs, baseline patient characteristics – which include patient demographic information and pre-operative patient characteristics, socio-economic status variables, peri-operative factors, and post-operative factors. These categories can be considered to have sequential timing – baseline patient characteristics and socio-economic status variables are determined prior to the operation, peri-operative factors are determined through the duration of the operation, and post-operative factors are determined after the operation is complete. In other words, baseline characteristics and SES are upstream of peri- and post-operative factors. Post-operative factors are downstream of baseline characteristics, SES, and peri-operative factors. The following sections describe these variables in more detail.

3.3.1 Patient Costs and Fiscal Year

The total per-person case cost for CABG procedures at the LHSC were used as the outcome measure in our analyses. As histogram of total costs can be found in Figure 1. The cost analysis is done from the perspective of the LHSC and all costs were adjusted for inflation and are measured in 2019 Canadian dollars using the annual average health and personal care consumer price index for each fiscal year.[75] Each fiscal year at the LHSC begins on April 1st and ends on March 31st of the following calendar year and is defined by the later calendar year. For example, fiscal year 2015 begins April 1st, 2014 and ends on March 31st, 2015. The fiscal year for each case was determined by the discharge date by the following algorithm: the fiscal year was considered to be equal to the year of discharge if the discharge month was less than or equal to 3, else the fiscal year was determined to be the discharge year plus one.

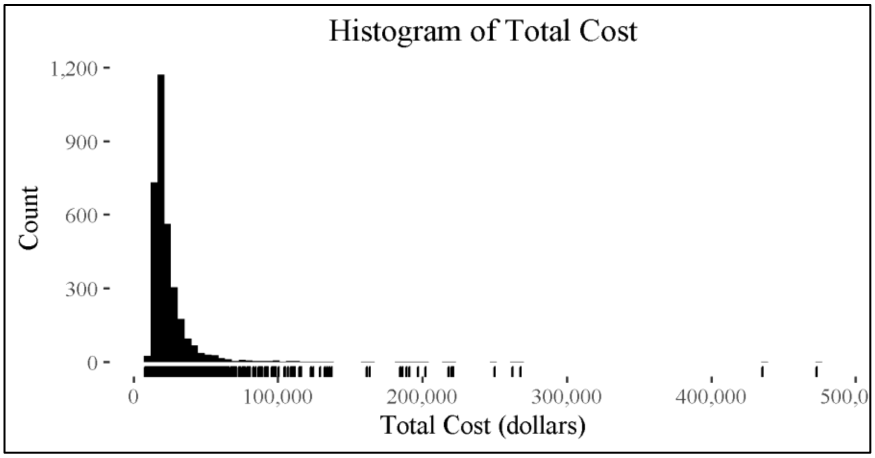

Figure 1 Histogram of Total Costs

3.2.2 Baseline Patient Characteristics

The following baseline patient characteristics were used for analyses: patient age, sex, diabetes, hypertension, hyperlipidemia, peripheral vascular disease, cerebrovascular disease, chronic obstructive pulmonary disease, cancer, dementia, dialysis, ischemic heart disease, heart failure, obesity, CCS class, NYHA class, and previous CABG procedure.

Patient age was calculated by subtracting the patient's birth year from the year that they were admitted to the hospital. If the month of admission was less than the patient's birth month then an additional year was subtracted. Patient age was centered in the analyses to increase interpretability. Patient sex was coded as 'M' for male and 'F' for female. Patient sex 'F' was used as the reference category for the analyses.

Co-morbid conditions, such as diabetes or history of cancer, were coded as "Y" if the condition was present upon admission and "N" if not. Cells that contained a null value were considered to indicate that the condition in question was not present upon admission. Therefore these were coded as "N" as well.

Body mass index was calculated using patient height and weight. This newly calculated body mass index variable was used to create an indicator for ‘obesity’. The patient was considered to suffer from obesity if the patient’s body mass index was greater than thirty.[28]

CCS classification and Acute Coronary Syndrome (ACS) classification was combined in the data. Since an ACS Classification is provided only for patients who had an acute coronary syndrome or myocardial infarction, these patients were considered to be grade IV in the CCS classification for angina pectoris and were recoded as such. Previous CABG was coded similarly to the co-morbid conditions – “Y” if the patient in question had undergone CABG previous to the current admission and “N” if the patient had not.

3.2.3 Socio-economic Status Variables

The ON-Marg was used as a proxy for patient-level socio-economic status (SES). It is advised to use data pertaining to the smallest spatial area available to minimize measurement error.[66] In the ON-Marg this corresponds to what is known as the dissemination area (DA), which is the smallest standard geographic area for which all census data are disseminated. However, due to data limitations the smallest geographical area we were able to use was the forward sortation area (FSA). The ON-Marg indices were aggregated to the FSA level by first determining the DA’s that are contained within each FSA, and then taking the population-weighted average of DA level scores. In our dataset, patients resided in one of 123 different FSA's. The number of people living in each FSA ranged from 1 person to 178 people. The FSA’s and the number of people living in each FSA are shown in Appendix B.

The ON-Marg indices can be used either as a variable on a continuous scale or categorized into quintiles.[66] To improve interpretability and comparability to the rest of Ontario, each individual's FSA was assigned a number from 1 to 5, corresponding to the provincial quintiles for each ON-Marg index.

3.2.3 Peri-operative and Post-operative Variables

The following peri-operative variables were used for analyses: minor complication, moderate complication, major complication, pump use, use of extracorporeal membrane oxygenation (ECMO), robotic surgery, procedure duration, blood product transfusion, and albumin transfusion.

Complications were classified as either minor, moderate, or major according to clinical guidance. Minor complication was coded as "Y" if the patient in question had one or more minor complications as identified by the corresponding ICD-10 codes, and "N" if not. Moderate complications and major complications were coded similarly. Coding was informed by published analyses of surgical complications.[76] The list of ICD-10 codes and classification (minor, moderate, major) is provided in Appendix C.

Pump use, ECMO, and robotic surgery were coded "Y" if the corresponding surgical assist device was used and "N" if not. Procedure duration was mean-centered to increase interpretability of the y-intercept in the analyses.

Blood product transfusion was coded "Y" if the patient had blood, plasma, and/or platelets transfusion and "N" if none of the patient did require transfusion of any of these products. Albumin transfusion was similarly coded "Y" if the patient had albumin transfusion and "N" otherwise.

The following post-operative variables were used for analyses: length of stay, use of more than one special care unit, return to the operating room, discharge disposition, and a long-stay indicator.

Length of stay was calculated by subtracting the date of admission from the date of discharge and converting the duration into days. The length of stay was also mean-centered in the analyses.

Those who had a discharge disposition of “Died in Facility”, “Died while on pass/leave”, or “Died, expired” were recoded as “Died”. Discharge dispositions of “Discharged to private home (no support service required)” and “Discharge to private home with support services” was recoded to “Home”. Discharge dispositions of “Left against medical advice (LAMA)” and “Left against medical advice (with or without sign-out, AWOL)” were recoded to “LAMA”. All other dispositions pertained to transfers to other departments or care facilities and were recoded to “transfer”.

A long stay indicator was created to be consistent with the long stay indicator in the CIHI costing models. The length of stay was considered to be ‘long stay’ if the length of stay was greater than 13 days.[45]

3.4 Statistical Analysis

Summary statistics were performed for all variables of interest excluding missing data where appropriate. 10-fold cross validation of generalized linear models fit with pre-operative patient characteristics, excluding cancer and dementia, was performed to select the best distribution and link function. Univariate models were fit to separately assess the association between patient demographics, socio-economic status, pre-operative patient characteristic, peri-operative, and post-operative variables and total procedure cost. Then five nested multivariate models were fit using the full dataset, excluding any cases with missing data. First, only baseline patient characteristics (excluding socio-economic factors) were considered (Model 1). Then the socio-economic factors were added (Model 2), followed by addition of peri-operative variables (Model 3). Post-operative variables were then added (Model 4). Finally, an interaction term between length of stay and a long stay indicator was added (Model 5). Model diagnostics were performed using the Akaike information criterion as well as assessment of each models' deviance residuals.

Mediation analysis was performed to assess mediation of peri-operative factor and select post-operative factors on total cost through length of stay. Length of stay was chosen as the mediating variable due to the strong relationship between length of stay and costs. A scatterplot of total costs versus length of stay shows a strong positive correlation (Figure 2). The strong relationship suggests that peri-operative factors such as complications or return to the operating room are associated with increased costs simply because they are associated with increased lengths of stay.

Finally, estimative models were developed using the same sets of covariates as the nested descriptive models. Whereas the descriptive models were used to identify relationships among covariates and outcomes, these estimative models were developed in order to determine how effectively baseline patient characteristics, socio-economic status variables, peri-operative factors and post-operative factors can be used to estimate costs. Such an approach would help to identify significant cost driver and determine whether there may be important variables not accounted for in the CIHI funding models used to inform reimbursement of CABG costs. The data were split into a training data set comprised of a random 80% sample of the data. The remaining 20% of the data were used as a validation set. The estimative models were trained using the training data set and validated using the validation set to assess model accuracy and precision. Mean relative squared error and bias were used to assess model performance. The respective formulas for these measures is shown in equations 1 and 2. All statistical analyses were performed in the R programming language version 3.6.3.

$$Mean\ relative\ squared\ error\ (MRSE) = \frac{1}{n}\sum_{k}\left(\hat{Y}_k - Y_k\right)^2/(|Y_k| + 1) \quad \textit{Eq 1}$$

$$Bias = \frac{1}{n}\sum_{k}\hat{Y}_k - \frac{1}{n}\sum_{k}Y_k \quad \textit{Eq 2}$$

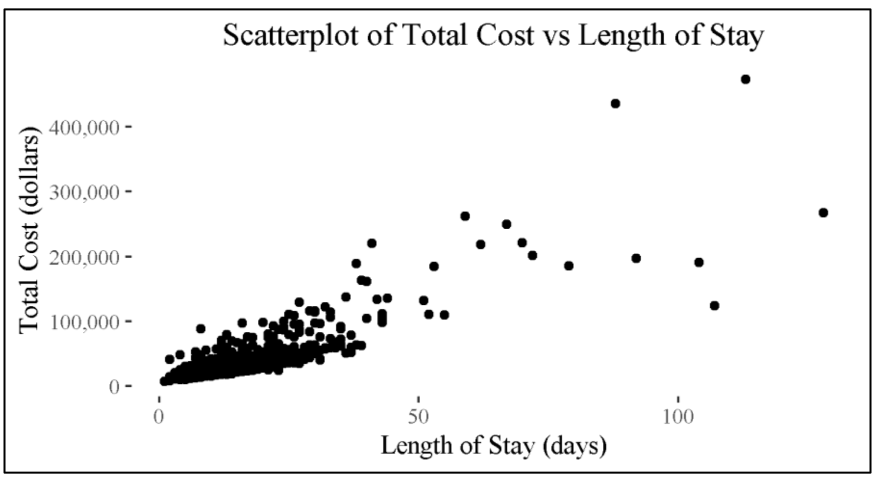

Figure 2: Scatterplot of Total Cost vs Length of Stay

Chapter 4

4 Results

The following chapter first provides descriptive statistics about the study cohort as well as summary statistics for case-costs per fiscal year. This is followed by the results of model selection using 10-fold cross validation. Then nested descriptive models are presented followed by select mediation analyses. Finally, the results from the estimative models are presented.

4.1 Descriptive Statistics

4.1.1 Breakdown of Costs by Fiscal Year

A total of 3,335 elective CABG surgeries, without concomitant valve procedure, were performed at the LHSC between April 1st, 2014 and March 31st, 2019. The fewest number of CABG surgeries was performed in 2019 (618) whereas the most surgeries were performed in 2017 (751). Adjusting for inflation, the average total cost was highest in the 2015 fiscal year at $26,619.43 expressed in 2019 Canadian dollars. The lowest average total cost was in 2018. On average, approximately half of the total cost (51.3%) is comprised of costs related to labour (variable and fixed). Most of the labour costs are variable costs that account for all unit-producing personnel (e.g. nursing staff) salary and benefits. The remaining cost is comprised mainly of materials and indirect costs (23.2% to 21.3% of total cost on average respectively). A full breakdown of average component costs and average total procedure cost as well as number of procedures performed stratified by fiscal year is shown in Table 1. This is also shown visually as a stacked bar chart in Figure 3.

Table 1: Coronary Artery Bypass Graft Surgeries by Fiscal Year and Associated Costs

	2015	2016	2017	2018	2019
Number of Procedures, n/total *N* (%)	625/3,335 (18.7)	706/3,335 (21.2)	751/3,335 (22.5)	635/3,335 (19.0)	618/3,335 (18.5)
Variable Direct Labour Plus, mean (SD)	$12,563.87 ($12,013.325)	$11,460.76 ($13,449.297)	$10,802.70 ($7,588.519)	$10,621.97 ($11,987.587)	$10,948.19 ($10,147.772)
Variable Direct Labour, mean (SD)	$12,554.01 ($12,003.509)	$11,460.24 ($13,447.302)	$10,797.51 ($7,584.522)	$10,621.72 ($11,986.658)	$10,948.18 ($10,147.756)
Variable Direct Other, mean (SD)	$9.76 ($11.64)	$0.42 ($2.544)	$5.12 ($6.125)	$0.23 ($2.868)	$0.01 ($0.120)
Variable Direct Material, mean (SD)	$5,644.27 ($3,745.677)	$5,674.24 ($3,282.558)	$5,319.22 ($2,029.816)	$4,763.96 ($3,422.747)	$5,069.28 ($2,634.993)
Variable Direct Material GS, mean (SD)	$3,916.72 ($2,782.973)	$3,940.20 ($2,949.781)	$3,774.88 ($1,398.381)	$3,169.77 ($2,695.559)	$3,461.18 ($1,768.236)
Variable Direct Material PSS, mean (SD)	$1,727.59 ($1,658.983)	$1,734.12 ($1,364.935)	$1,554.34 ($1,296.509)	$1,594.17 ($1,804.938)	$1,608.14 ($1,538.627)
Fixed Direct, mean (SD)	$2,972.06 ($2,428.626)	$3,130.37 ($2,414.499)	$2,631.84 ($1,347.984)	$2,513.11 ($2,028.653)	$2,756.18 ($1,784.280)
Fixed Direct Labour, mean (SD)	$2,237.56 ($2,014.150)	$1,881.80 ($1,877.453)	$1,687.50 ($1,051.858)	$1,659.69 ($1,629.970)	$1,692.41 ($1,438.397
Fixed Direct BEG, mean (SD)	$758.70 ($343.295)	$785.00 ($337.073)	$759.57 ($228.797)	$715.91 ($310.709)	$933.14 ($293.422)
Fixed Direct Other, mean (SD)	$-24.13 ($220.720)	$463.65 ($355.044)	$184.72 ($130.330)	$137.55 ($136.826)	$130.62 ($149.030)
Fixed Indirect, mean (SD)	$5,439.12 ($5,088.411)	$4,938.03 ($5,621.781)	$5,658.21 ($3,846.735)	$5,215.39 ($5,755.064)	$5,769.21 ($5,114.453)
Total, mean (SD)	$26,619.43 ($22,558.051)	$25,203.42 ($24,382.201)	$24,411.92 ($14,299.422)	$23,114.49 ($22,599,781)	$24,542.87 ($18,891.325)

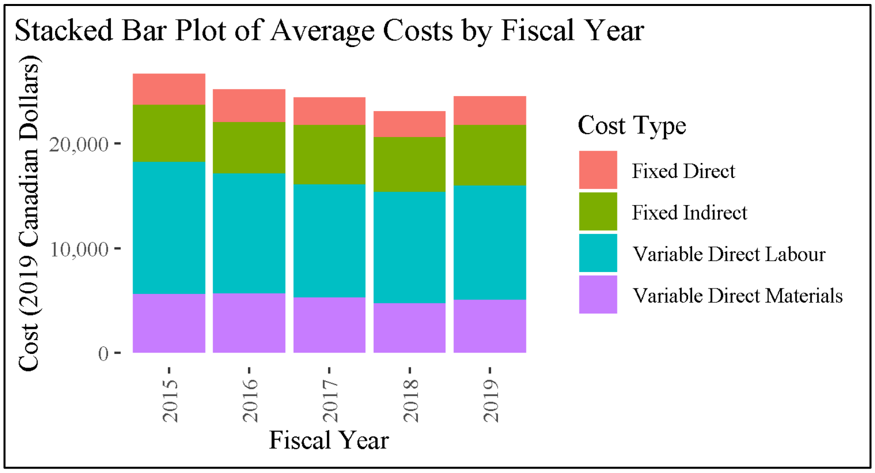

Figure 3 Stacked Bar Plot of Average Costs by Fiscal Year

4.1.2 Baseline Characteristics,

Most CABG patients at the LHSC were male (79%) and had an average age of 66.4 years (standard deviation: 9.45 years). Additionally, a large proportion of these patients suffered from obesity (41.7%), ischemic heart disease (42.4%), hypertension (85.8%), hyperlipidemia (81.5%), and diabetes (40.6%). Of the patients who underwent elective CABG without concomitant valve procedure, 15.1% suffered from chronic obstructive pulmonary disease and 13.1% suffered from peripheral vascular disease. A full list of summary statistics for baseline characteristics is tabulated in Table 2.

Table 2: Baseline Characteristics of CABG Patients

Patient Demographics			N = 3,335
	Age (years), mean (SD)		66.4 (9.45)
	Sex, n (%)	Male	2,634 (79.0)
Socio-economic Variables			
	Instability, n (%)	1	791 (23.7)
		2	593 (17.8)
		3	880 (26.4)
		4	594 (17.8)
		5	458 (13.7)
		NA	19 (0.6)
	Material Deprivation, n (%)	1	314 (9.4)
		2	809 (24.3)
		3	619 (18.6)
		4	604 (18.1)
		5	970 (29.1)

	NA	19 (0.6)
Dependency, n (%)	1	19 (0.6)
	2	469 (14.1)
	3	702 (21.0)
	4	1,564 (46.9)
	5	562 (16.9)
	NA	19 (0.6)
Ethnic Concentration, n (%)	1	1,112 (33.3)
	2	1,056 (31.7)
	3	568 (17.0)
	4	475 (14.2)
	5	105 (3.1)
	NA	19 (0.6)
Pre-operative Patient Characteristics		
Canadian Cardiovascular Society Grading of Angina Pectoris, n (%)	No Angina	179 (5.4)
	1	254 (7.6)
	2	767 (23.0)
	3	687 (20.6)
	4	1,411 (42.3)
	NA	37 (1.1)
New York Heart Association Classification of Heart Failure, n (%)	No Classification	1,450 (43.5)
	1	1,060 (31.8)
	2	458 (13.7)
	3	276 (8.3)
	4	52 (1.6)
	NA	39 (1.2)
Had Previous CABG, n (%)	Yes	35 (1.0)
	NA	73 (2.2)
Has Obesity, n (%)	Yes	1,390 (41.7)
	NA	18 (0.5)
Has Ischemic Heart Disease, n (%)	Yes	1,413 (42.4)
Has Hypertension, n (%)	Yes	2,862 (85.8)
Has Hyperlipidemia, n (%)	Yes	2,718 (81.5)
Has History of Heart Failure, n (%)	Yes	261 (7.8)
Has Diabetes, n (%)	Yes	1,355 (40.6)
Has Cerebrovascular Disease, n (%)	Yes	366 (11.0)
Has Chronic Obstructive Pulmonary Disease, n (%)	Yes	503 (15.1)
Has History of Dialysis, n (%)	Yes	111 (3.3)
Has History of Cancer, n (%)	Yes	43 (1.3)
Has Dementia, n (%)	Yes	32 (1.0)
Has Peripheral Vascular Disease, n (%)	Yes	437 (13.1)

4.1.3 Peri-operative and Post-operative Factors

Most CABG procedures at the LHSC were performed on-pump (91.2%) with about a quarter of all procedures requiring blood product transfusion (27.8%). Of all CABG patients, 22% received an albumin transfusion. The duration of procedures was on average 296 minutes (4.9 hours) and patients had an average length of stay of 9.4 days. Most patients were discharged to their private homes with or without additional support (93.9%). Summary statistics for peri-operative and post-operative factors are tabulated in Table 3.

Table 3: Peri-operative and Post-operative Factors

Peri-operative Factors		N = 3,335
Use of Heart-Lung Machine, n (%)		3,040 (91.2)
Use of Surgical Robot, n (%)		148 (4.4)
Use of Extracorporeal Membrane Oxygenation, n (%)		3 (0.1)
Received Blood Product Transfusion, n (%)		926 (27.8)
Received Albumin Transfusion, n (%)		733 (22.0)
Had Minor Complications, n (%)		529 (15.9)
Had Moderate Complications, n (%)		683 (20.5)
Had Major Complications, n (%)		134 (4.0)
Procedure Duration (minutes), mean (SD)		296.1 (61.98)
Pump Time (minutes), mean (SD)		76.8 (38.85)
Post-operative Factors		N = 3,335
Length of Stay (days), mean (SD)		9.4 (7.52)
Return to Operating Room, n (%)		71 (2.1)
Need for More than One Special Care Unit, n (%)		552 (16.5)
Discharge Disposition, n (%)	Home	3,131 (93.9)
	Died	39 (1.2)
	Left Against Medical Advice	5 (0.1)
	Transfer to Other Facility or Department	160 (4.8)

4.2 Model Selection by Cross Validation

10-fold cross validation using the mean relative squared error as the cost function was used to choose the most appropriate distribution and link function to use to model total cost of CABG. A total of eight models with different distribution and link functions were considered adjusting for the following variables: age, sex, instability quintile, deprivation quintile, dependency quintile, ethnic concentration quintile, diabetes, hypertension, hyperlipidemia, peripheral vascular disease, cerebrovascular disease, chronic obstructive pulmonary disease, ischemic heart disease, heart failure, obesity, CCS class, total cost, and fiscal year. Certain variables, such as cancer or dementia, were omitted due to having factor classes that accounted for less than 5% of cases. Poisson, Overdispersed Poisson, Gamma, and Negative Binomial families were considered. The log and identity links were the only link functions considered. The mean relative squared error and the adjusted mean relative squared error was tabulated for each model (Table 4). Adjustment was made to account for bias introduced by not performing leave-one-out cross validation.[77] The distribution families that had the lowest mean relative squared error were the Gamma and Negative Binomial families. The identity-link was consistently better than the log-link. Overall, the Negative Binomial GLM with Identity-link had the lowest MRSE (unadjusted: 4,287.966, adjusted: 4,282.448). However, this type of GLM is not often used in the literature. The Gamma GLM is more widely used in cost regression and the error terms were close in magnitude to the negative binomial GLMs. Due to this familiarity and small difference in precision, the Gamma GLM with identity-link was used for descriptive and predictive analyses.

Table 4: Cross-validation Errors by Family and Link Function

	MRSE	**Adjusted MRSE**
Poisson with Log-Link	4,496.294	4,475.001
Poisson with Identity-Link	4,404.463	4,396.197
Overdispersed Poisson with Log-Link	4,399.276	4,385.982
Overdispersed Poisson with Identity-Link	4,381.598	4,374.961
Gamma with Log-Link	4,336.423	4,327.780
Gamma with Identity-Link	4,292.067	4,286.107
Negative Binomial with Log-Link	4,299.487	4,295.185
Negative Binomial with Identity-Link	4,287.966	4,282.448

4.3 Univariate Generalized Linear Models

Each variable was entered into a univariate GLM regression, with gamma distribution and identity link, with total cost as the outcome. A full list of coefficients is presented in Table 5 – β_0 refers to the intercept term, and β_1 refers to the variable coefficient. Coefficients were considered to be statistically significant if the p-value was less than the confidence level of 0.05. Statistical significance is denoted by an asterisk (*). According to the univariate generalized linear models, several baseline characteristics were found to be associated with significant increase or decrease of total procedure costs. Age was associated with increase in total costs (β = \$196.68 (\$130.980 to \$261.069), p-value <0.0001). It was also found that total costs were lower for Male patients than Female patients (β_{Male} = -\$2,632.20 (-\$4,525.166 to -\$846.739), p-value = 0.005). Material deprivation and ethnic concentration largely showed no significant association with total cost. However, patients living within forward sortation areas that pertained to higher instability had significantly higher total costs. On the other hand, higher dependency was associated with lower cost. Several co-morbid conditions were significantly associated with higher CABG costs. Ischemic heart disease, hypertension, history of heart failure, diabetes, cerebrovascular disease, chronic obstructive pulmonary disease, history of cancer, dementia, and history of dialysis were all associated with higher CABG costs. Particularly, the average costs of CABG patients who suffered from dementia were \$44,322.50 (95% confidence interval: \$28,244.140 to \$67,667.840) higher than the average costs of patients who did not suffer from dementia. Additionally, the total costs for patients who suffered from severe angina according to CCS class (grade IV) were far greater than patients who did not suffer from angina (grade 0). Patients with a higher classification of heart failure (New York Heart Association grades 3 and 4) had higher costs on average than patients where no classification was assigned.

Of the peri-operative and post-operative factors, use of the heart-lung machine and leaving against medical advice was not significantly associated with CABG costs. The average cost of robotic CABG procedures was lower than regular CABG ($\beta_{Robotic}$ = -$6,452.30 (-$8,852.691 to -$3,643.508), p-value = <0.0001). The other peri-operative and post-operative variables were associated with increases in cost. In particular, the average cost for cases that required the use of extracorporeal membrane oxygenation (ECMO) was much greater than procedures that did not use ECMO (β_{ECMO} = $212,971.00 ($85,784.070 to $647,980.090), p-value = 0.0478). Peri-operative and post-operative complications were also associated with significantly higher total costs. Procedures with at least one major complication had average total costs that were $37,945.10 (95% confidence interval: $31,468.260 to $45,472.540) higher than those that had not had a major complication. Cases that required a return to the operating room had average costs that were $47,379.20 (95% confidence interval: $36,477.850 to $61,063.230) higher than those that did not require any return to the operating room. Discharge disposition also had a significant association with cost. In particular, cases where the patient died had an average total cost that was $68,389.90 ($53,017.007 to $88,213.450) higher than patients who were discharged to their homes.

Table 5: Coefficients of Univariate Generalized Linear Models of Factors on Total Cost

		β_0 (95% CI)	β_1 (95% CI)	p-value
Patient Demographics				
Age		24,764.62 (24,085.655 to 25,469.455)	196.68 (130.980 to 261.069)	<0.0001*
Sex	Male	26,855.00 (25,256.891 to 28,590.868)	-2,632.20 (-4,525.166 to -846.739)	0.0050*
Socio-economic Status Variables				
Instability	1	23,872.40 (22,625.563 to 25,212.596)	-298.40 (-2,163.930 to 1,575.933)	0.7540
	2	23,872.40 (22,625.563 to 25,212.596)	523.40 (-1,520.534 to 2,616.969)	0.6192
	3	-	-	-
	4	23,872.40 (22,625.563 to 25,212.596)	3,367.90 (1,186.854 to 5,621.351)	0.0029*
	5	23,872.40 (22,625.563 to 25,212.596)	2,132.70 (-160.867 to 4,534.015)	0.0743
Material Deprivation	1	23,733.90 (22,231.236 to 25,375.108)	1,670.90 (-1,093.596 to 4,595.991)	0.2480
	2	23,733.90 (22,231.236 to 25,375.108)	1,261.40 (-889.582 to 3,388.593)	0.2470
	3	-	-	-
	4	23,733.90 (22,231.236 to 25,375.108)	1,530.20 (-774.952 to 3,852.406)	0.1940
	5	23,733.90 (22,231.236 to 25,375.108)	1,072.80 (-997.939 to 3,099.659)	0.3040
Dependency	1	27,375.30 (25,787.663 to 29,096.004)	-1,789.10 (-9,490.579 to 10,552.109)	0.7146
	2	27,375.30 (25,787.663 to 29,096.004)	-2,802.20 (-5,244.940 to -321.582)	0.0253*
	3	-	-	-
	4	27,375.30 (25,787.663 to 29,096.004)	-3,255.50 (-5,219.937 to -1,376.170)	0.0009*
	5	27,375.30 (25,787.663 to 29,096.004)	-3,786.10 (-6,086.196 to -1,485.828)	0.0012*
Ethnic Concentration	1	26,164.65 (24,466.837 to 28,023.290)	-1,623.84 (-3,809.365 to 474.521)	0.1365
	2	26,164.65 (24,466.837 to 28,023.290)	-2,226.00 (-4,411.879 to -126.557)	0.0414*
	3	-	-	-
	4	26,164.65 (24,466.837 to 28,023.290)	-63.17 (-2,681.935 to 2,586.085)	0.9624
	5	26,164.65 (24,466.837 to 28,023.290)	-3,479.77 (-7,226.783 to 845.346)	0.0879
Pre-operative Characteristics				
CCS Classification of Angina Pectoris	0	-	-	-
	1	21,467.53 (19,236.892 to 24,057.401)	-866.64 (-4,029.552 to 2,173.994)	0.581
	2	21,467.53 (19,236.892 to 24,057.401)	-1,159.15 (-3,952.348 to 1,350.768)	0.389
	3	21,467.53 (19,236.892 to 24,057.401)	-25.41 (-2,865.515 to 2,549.042)	0.985
	4	21,467.53 (19,236.892 to 24,057.401)	8,033.67 (5,210.320 to 10,579.362)	<0.0001*
NYHA Classification of Heart Failure	0	-	-	-
	1	24,276.60 (23,327.695 to 25,277.761)	-1,419.40 (-2,863.971 to 38.545)	0.0551

	2	24,276.60 (23,327.695 to 25,277.761)	411.10 (-1,549.509 to 2,488.490)	0.6892
	3	24,276.60 (23,327.695 to 25,277.761)	4,517.20 (1,825.511 to 7.489.687)	0.0017*
	4	24,276.60 (23,327.695 to 25,277.761)	19,576.40 (11,390.784 to 30,391.588)	<0.0001*
Previous Coronary Artery Bypass Graft		24,495.00 (23,811.929 to 25,204.400)	7,468.40 (89.715 to 18,064.210)	0.0944
Obesity		24,503.10 (23,607.302 to 25.444.926)	544.70 (-883.977 to 1,993.142)	0.458
Ischemic Heart Disease		21,358.90 (20,638.109 to 22,124.719)	8,063.30 (6,665.733 to 9,498.333)	<0.0001*
Hypertension		22,465.20 (20,866.540 to 24,231.347)	2,693.40 (777.713 to 4,475.446)	0.0042*
Hyperlipidemia		25,944.10 (24,297.606 to 27,742.875)	-1,432.90 (-3,383.231 to 396.237)	0.1370
History of Heart Failure		22,877.30 (22,359.520 to 23,411.270)	24,276.40 (20,703.09 to 28,233.660)	<0.0001*
Diabetes		23,804.90 (22,952.700 to 24,699.810)	2,392.50 (951.940 to 3,861.640)	0.0013*
Cerebrovascular Disease		23,858.50 (23,189.549 to 24,553.410)	8,369.00 (5,784.618 to 11,218.830)	<0.0001*
Chronic Obstructive Pulmonary Disease		24,043.20 (23,3334.729 to 24,780.621)	4,864.60 (2,761.041 to 7,139.997)	<0.0001*
History of Cancer		24,626.60 (23,935.437 to 25,344.730)	11,638.70 (3,856.404 to 22,485.320)	0.0123*
Dementia		24,351.50 (23,695.080 to 25.032.410)	44,322.50 (28,244.140 to 67,667.840)	<0.0001*
History of Dialysis		24,044.40 (23,446.350 to 24,663.000)	22,006.90 (16,225.150 to 28,926.430)	<0.0001*
Peripheral Vascular Disease		23,970.70 (23,265.263 to 24,705.012)	6,152.40 (3,817.503 to 8,704.445)	<0.0001*
Peri-operative Factors				
Use of Heart-Lung Machine		23,541.00 (21,411.442 to 25,962.964)	1,356.00 (-1,171.347 to 3,621.623)	0.2660
Use of Surgical Robot		25,062.90 (24, 355.534 to 25,797.972)	-6,452.30 (-8,852.691 to -3,643.508)	<0.0001*
Use of Extracorporeal Membrane Oxygenation		24,585.00 (23,941.950 to 25,251.590)	212,971.00 (85,784.070 to 647,980.090)	0.0478*
Blood Product Transfusion		20,873.70 (20,340.940 to 21,425.200)	14,045.70 (12,520.430 to 15,640.460)	<0.0001*
Albumin Transfusion		21,552.60 (21,024.640 to 22,098.430)	14,653.10 (12,918.550 to 16,482.780)	<0.0001*
Had Minor Complication		21,561.50 (21,109.850 to 22,026.230)	20,275.20 (18,238.570 to 22,438.750)	<0.0001*
Had Moderate Complication		21,322.80 (20,847.210 to 21,812.990)	16,869.70 (15,143.450 to 18,688.990)	<0.0001*
Had Major Complication		23,252.50 (22,720.650 to 23,801.050)	37,945.10 (31,468.260 to 45,472.540)	<0.0001*
Procedure Duration		24,732.90 (24,040.073 to 25,453.015)	62.926 (50.237 to 75.786)	<0.0001*
Post-operative Factors				
Length of Stay		24,317.16 (24,104.422 to 24,532.633)	1,773.73 (1,726.978 to 1,820.992)	<0.0001*
Return to Operating Room		23,768.30 (23,179.670 to 24,377.020)	47,379.20 (36,477.850 to 61,063.230)	<0.0001*
Use of More than One Special Care Unit		21,547.40 (21,017.950 to 22,094.830)	19,515.90 (17,228.500 to 21,965.990)	<0.0001*
Discharge Disposition	Home	-	-	-
	Died	22,758.60 (22,281.664 to 23,249.340)	68,389.90 (53,017.007 to 88,213.450)	<0.0001*
	Left Against Medical Advice	22,758.60 (22,281.664 to 23,249.340)	8,517.20 (-3,574.994 to 33,309.440)	0.316
	Transfer	22,758.60 (22,281.664 to 23,249.340)	25,139.40 (20,874.419 to 29,964.460)	<0.0001*

4.4 Comparison of Descriptive Models

4.4.1 Descriptive Model Results

Using a multiple variable GLM regression model, with gamma distribution and identity link, we tested five descriptive models with total cost as the outcome. Model 1 only considered basic patient demographic information as well as pre-operative patient characteristics, such as co-morbid conditions. A female patient who had their procedure performed in the 2015 fiscal year of average age, who had no co-morbidities present upon admission, who did not suffer from angina (CCS class 0) nor was assigned a NYHA classification of heart failure, who had not had a previous CABG procedure had an average cost of $19,608.30 (95% confidence interval: $17,237.611 to $22,089.309). Diabetes, hypertension, and hyperlipidemia did not have a statistically significant impact on total cost. CCS class 1 to 3, NYHA class 1 and 2, and having had the procedure in 2016, 2017, and 2019 were also found not to have a statistically significant impact on total cost. Holding all other factors equal, having the procedure in 2018 was found to be associated with a decrease in costs of $2,072.37 (95% confidence interval: $-3,353.230 to $-804.680) compared to having had the procedure in 2015. Compared to female patients, male patients had costs that were $1,072.64 (95% confidence interval; $-2,144.458 to $-41.669) greater. With the exception of diabetes, hypertension, and hyperlipidemia, the presence of co-morbid conditions upon admission were associated with an increase in total procedure costs. In particular, having a history of heart failure was associated with an increase in costs of $16,301.15 ($13,512.115 to $19,326.655) compared to not having a history of heart failure. Having had dementia upon admission was associated with an increase in costs of $33,323.99 ($22,762.827 to $46,840.094). A full list of model coefficients for model 1 are tabulated in Table 6a.

Table 6a: Table of Results for Descriptive Models (Model 1)

		Model 1 **β (95% CI)**	p-value
Intercept		19,608.30 (17,237.611 to 22,089.309)	<0.0001*
Age		127.14 (85.748 to 168.104)	<0.0001*
Sex		-1,072.64 (-2,144.458 to -41.669)	0.0433*
Diabetes		342.47 (-508.383 to 1,202.025)	0.4334
Hypertension		543.37 (-637.878 to 1,676.837)	0.3597
Hyperlipidemia		-831.20 (-2,000.761 to 293.470)	0.1561
Peripheral Vascular Disease		1,722.68 (398.189 to 3,125.786)	0.0132*
Cerebrovascular Disease		2,457.99 (968.044 to 4,048.218)	0.0016*
Chronic Obstructive Pulmonary Disease		1,413.79 (234.043 to 2,655.730)	0.0200*
History of Cancer		9,394.17 (4,565.455 to 15,391.238)	0.0006*
Dementia		33,323.99 (22,762.827 to 46,840.094)	<0.0001*
History of Dialysis		9,915.05 (6,383.668 to 13,981.583)	<0.0001*
Ischemic Heart Disease		2,749.84 (1,641.579 to 3,857.417)	<0.0001*
Heart Failure		16,301.15 (13,512.115 to 19,326.655)	<0.0001*
Obesity		858.86 (26.706 to 1,697.657)	0.0431*
CCS Class	0	-	-
	1	67.57 (-1,975.325 to 2,057.275)	0.9481
	2	-11.46 (-1,799.146 to 1,647.664)	0.9898
	3	-12.21 (-1,829.543 to 1,684.561)	0.9893
	4	4,602.98 (2,662.554 to 6,440.162)	<0.0001*
NYHA	0	-	-
	1	-226.63 (-1,122.564 to 674.263)	0.6222
	2	-41.55 (-1,245.140 to 1,208.923)	0.9474
	3	2,127.06 (483.602 to 3,883.691)	0.0133*
	4	7,776.17 (2,806.539 to 13,853.836)	0.0038*
Previous CABG		4,750.63 (471.288 to 10,197.787)	0.0501*
Fiscal Year	2015	-	-
	2016	-580.86 (-1,890.230 to 719.545)	0.3820
	2017	-817.47 (-2,099.074 to 451.140)	0.2091
	2018	-2,072.37 (-3,353.230 to -804.680)	0.0014*
	2019	-259.75 (-1,600.885 to 1,076.835)	0.7037

*: statistically significant

Inclusion of ecological socio-economic factors status (model 2), only affected the variance associated with the impact of patient sex on total costs. Patients from forward sortation areas in the median instability quintile (quintile 3) had costs that were not statistically significantly different than patients from lower instability quintiles (1 or 2). However, higher instability quintiles were associated with increased costs compared to the median quintile of $1,601.09 (95% confidence interval: $244.451 to $2,978.812) and $2,226.72 (95% confidence interval: $615.014 to $3,850.156) for quintiles 4 and 5 respectively. Material deprivation was not statistically significantly associated with costs. Dependency quintile 4 was the only one that was found to have costs that were statistically significantly different than quintile 3 being lower by $1,230.47 (95% confidence interval: $-2,390.982 to $-96.139). Quintile 5 was found to have costs that were $1,000.39 (95% confidence interval: $-2,360.318 to $363.303) lower holding all other variables constant. All ethnic concentration quintiles were found not to be statistically significantly different to quintile 3. However, ethnic concentration quintile 5 compared to the median quintile was $2,195.43 (95% confidence interval: $-4,545.145 to $350.808) lower. The impacts of other variables on cost remained the same compared to model 1.

Model 3 includes peri-operative variables such as procedure duration and complication in addition to baseline demographics, pre-operative characteristics, and socio-economic factors. Patient sex, presence of peripheral vascular disease, cerebrovascular disease, and obesity upon admission were no longer found to have a statistically significant impact on cost following addition of peri-operative variables. Having had a previous CABG procedure was also not statistically significant but the sign of the coefficient was now negative. Having had a previous CABG procedure was now associated with lower costs of $2,779.74 ($-5,524.904 to $520.125). All peri-operative variables were statistically significant. Both use of the heart-lung machine and robotic surgery were found to be associated with lower costs of $1,413.15 (95% confidence interval: $-2,764.824 to $-142.769) and $2,178.09 (95% confidence interval: $-3,828.854 to $-521.718) respectively. All other variables were associated with an increase in costs. In particular, having had a major complication during the procedure associated with an increase in costs of $14,456.77 (95% confidence interval: $11,134.313 to $18,103.230) holding all other variables constant. Extracorporeal membrane oxygenation was associated with an immense increase in costs of $174,633.38 ($96,670.425 to $313,589.969). Interestingly, the impact of fiscal year on costs became statistically significant. A full list of coefficients for model 2 and model 3 can be found in Table 6b.

Table 6b: Table of Results for Descriptive Models (Model 2 and 3)

		Model 2		Model 3	
		β (95% CI)	p-value	**β (95% CI)**	p-value
Intercept		19,211.83 (16,272.227 to 22,240.517)	<0.0001*	18,847.51 (16,437.298 to 21,318.452)	<0.0001*
Age		129.57 (87.940 to 170.780)	<0.0001*	61.29 (30.180 to 92.231)	0.0002*
Sex		-1,017.82 (-2,075.600 to 0.415)	0.0521	-111.46 (-848.415 to 60.436)	0.7644
Instability	1	-203.62 (-1,599.301 to 1,199.798)	0.7745	-284.03 (-1,270.709 to 706.081)	0.5744
	2	890.31 (-645.052 to 2,443.659	0.2573	317.07 (-765.813 to 1,408.479)	0.5701
	3	-	-	-	-
	4	1,601.09 (244.451 to 2,978.812)	0.0205*	665.91 (-274.347 to 1,615.782)	0.1681
	5	2,226.72 (615.014 to 3,850.156)	0.0067*	1,199.07 (61.802 to 2,343.239)	0.0389*
Material Deprivation	1	765.58 (-1,050.922 to 2,622.990)	0.4107	1,066.05 (-219.857 to 2,375.010)	0.1072
	2	135.96 (-1,210.084 to 1,467.084)	0.8433	572.12 (-373.081 to 1,509.513)	0.2396
	3	-	-	-	-
	4	730.60 (-687.629 to 2,156.684)	0.3177	973.53 (-35.887 to 1,986.515)	0.0600
	5	-406.05 (-1,920.628 to 1,082.983)	0.5968	241.14 (-813.618 to 1,280.791)	0.6540
Dependency	1	2,687.93 (-2,389.925 to 9,392.571)	0.3478	865.47 (-2,770.277 to 5,378.328)	0.6665
	2	-441.24 (-1,931.415 to 1,063.644)	0.5647	-141.21 (1,198.780 to 925.224)	0.7952
	3	-	-	-	-
	4	-1,230.47 (-2,390.982 to -96.139)	0.0352*	-834.52 (-1,643.100 to -39.812)	0.0416*
	5	-1,000.39 (-2,360.318 to 363.303)	0.1522	-683.67 (-1,649.439 to 284.802)	0.1673
Ethnic Concentration	1	502.64 (-943.111 to 1,928.465)	0.4935	322.30 (-701.876 to 1,335.627)	0.5363
	2	-394.34 (-1,666.898 to 855.025)	0.5465	-424.04 (-1,325.094 to 464.546)	0.3612
	3	-	-	-	-
	4	446.62 (-1,026.077 to 1,936.982)	0.5503	411.68 (-634.263 to 1,466.696)	0.4402
	5	-2,195.43 (-4,545.145 to 350.808)	0.0802	-1,881.44 (-3,563.762 to -93.573)	0.0349*
Diabetes		439.87 (-400.960 to 1,289.075)	0.3078	275.72 (-317.517 to 873.420)	0.3662
Hypertension		537.87 (-624.689 to 1,654.479)	0.3571	580.50 (-252.262 to 1,388.011)	0.1656
Hyperlipidemia		-750.39 (-1,902.756 to 358.896)	0.1929	-556.61 (-1,374.942 to 238.400)	0.1750
Peripheral Vascular Disease		1,622.35 (310.718 to 3,009.566)	0.0180*	468.54 (-441.220 to 1,416.903)	0.3178
Cerebrovascular Disease		2,399.55 (928.271 to 3,967.287)	0.0017*	660.10 (-355.475 to 1,726.217)	0.2100
Chronic Obstructive Pulmonary Disease		1,452.62 (286.765 to 2,678.178)	0.0154*	633.58 (-176.235 to 1,474.378)	0.1294
History of Cancer		9,418.35 (4,643.156 to 15,323.969)	0.0005*	5,267.03 (1,945.033 to 9,184.352)	0.0028*
Dementia		33,363.35 (22,959.865 to 46,627.701)	<0.0001*	19,225.84 (11,446.148 to 28,544.750)	<0.0001*

History of Dialysis		9,776.44 (6,305.666 to 13,764.980)	<0.0001*	5,024.31 (2,769.312 to 7,533.270)	<0.0001*
Ischemic Heart Disease		2,609.31 (1,534.228 to 3,701.803)	<0.0001*	2,134.80 (1,369.775 to 2,909.656)	<0.0001*
Heart Failure		15,922.11 (13,179.723 to 18,891.358)	<0.0001*	7,552.22 (5,753.856 to 9,467.625)	<0.0001*
Obesity		841.95 (20.969 to 1,669.148)	0.0448*	185.15 (-400.510 to 774.115)	0.5376
CCS Class	0	-	-	-	-
	1	305.98 (-1,712.259 to 2,272.876)	0.7651	-155.18 (-1,573.516 to 1,235.290)	0.8300
	2	187.80 (-1,576.476 to 1,828.285)	0.8310	-28.21 (-1,268.253 to 1,145.494)	0.9639
	3	197.35 (-1,595.756 to 6,548.296)	0.8255	50.35 (-1,208.811 to 1,247.179)	0.9366
	4	4,745.61 (2,841.680 to 6,548.296)	<0.0001*	3,774.67 (2,432.085 to 5,063.125)	<0.0001*
NYHA	0	-	-	-	-
	1	-214.13 (-1,096.637 to 673.078)	0.6373	139.71 (-489.473 to 771.047)	0.6664
	2	-38.74 (-1,225.614 to 1,193.316)	0.9503	85.19 (-760.335 to 954.165)	0.8467
	3	1,981.98 (359.605 to 3,713.471)	0.0191*	614.76 (-501.636 to 1,785.677)	0.2883
	4	8,037.58 (3,093.530 to 14,058.537)	0.0026*	5,426.69 (1,961.613 to 9,440.372)	0.0023*
Previous CABG		5,156.71 (925.210 to 10,515.155)	0.0310*	-2,779.74 (-5,524.904 to 520.125)	0.0710
Had Minor Complications		-	-	5,564.62 (4,312.991 to 6,867.602)	<0.0001*
Had Moderate Complications		-	-	4,177.08 (3,186.250 to 5,205.751)	<0.0001*
Had Major Complications		-	-	14,456.77 (11,134.313 to 18,103.230)	<0.0001*
Use of Heart-Lung Machine		-	-	-1,413.15 (-2,764.824 to -142.769)	0.0301*
ECMO		-	-	174,633.38 (96,670.425 to 313,589.969)	0.0007*
Robotic		-	-	-2,178.09 (-3,828.854 to -521.718)	0.0087*
Procedure Duration		-	-	34.11 (27.894 to 40.370)	<0.0001*
Blood Product Transfusion		-	-	2,241.55 (1,374.909 to 3,130.610)	<0.0001*
Albumin Transfusion		-	-	2,980.29 (2,057.502 to 3,933.568)	<0.0001*
Fiscal Year	2015	-	-	-	-
	2016	-525.95 (-1,814.318 to 753.389)	0.4215	-942.70 (-1,858.706 to -32.309)	0.0433*
	2017	-624.07 (-1,891.912 to 631.181)	0.3324	-1,158.19 (-2,058.014 to -265.535)	0.0116*
	2018	-1,927.23 (-3,192.100 to -675.055)	0.0027*	-2,573.53 (-3,472.041 to -265.535)	<0.0001*
	2019	-134.66 (-1,459.593 to 1,185.950)	0.8419	-977.44 (-1,922.053 to -35.490)	0.0431*

*: statistically significant

In addition to previous variables, model 4 included post-operative variables such as length of stay and discharge disposition. History of cancer, having had a moderate complication, and use of the heart-lung machine were found to no longer be statistically significant. The impact of dementia on total costs was much smaller than in model 3 increasing costs by $3,246.92 (95% confidence interval: $627.192 to $6,149.922). Interestingly, there were several variables where the sign of the coefficient flipped compared to model 3. The coefficients for age, ischemic heart disease, and CCS class 4 compared to CCS class 0 all changed from positive to negative. Due to the complexity of the relationships between each variable, further investigation is required to uncover the reasons for these changes. All of the post-operative variables were found to have a statistically significant impact on cost except patients who left against medical advice (LAMA). Post-operative variables were associated with significant increase in costs. Each additional day above the average length of stay added $1,467.82 (95% confidence interval: $1,419.350 to $1,516.651) to the total procedure cost. Return to the operating room and having to use more than one special care unit added $4,270.05 (95% confidence interval: $3,875.210 to $7,797.788) and $5,768.44 (95% confidence interval: $3,730.316 to $4,818.374) to the total cost. Patient death added $19,027.38 (95% confidence interval: $15,539.608 to $22,780.239) to total cost compared to those who were discharged to their home with or without supportive care, holding all other variables constant. Model 5 includes an additional interaction term between length of stay and a long stay indicator. This interaction was statistically significant and added $590.08 (95% confidence interval: $488.838 to $691.539) per diem compared to patients that were not considered to be long stay. Full coefficients for model 4 and 5 are listed in Table 6c.

Table 6c: Table of Results for Descriptive Models (Models 4-5)

		Model 4		Model 5	
		β (95% CI)	p-value	**β (95% CI)**	p-value
Intercept		23,654.90 (22,581.456 to 24,739.248)	<0.0001*	22,288.74 (21,223.816 to 23,363.283)	<0.0001*
Age		-17.57 (-31.688 to -3.472)	0.0153*	-8.82 (-22.552 to 4.891)	0.2100
Sex		227.60 (-88.037 to 539.373)	0.1574	162.44 (-143.333 to 464.631)	0.2970
Instability	1	44.51 (-386.164 to 475.930)	0.8402	38.83 (-379.207 to 457.468)	0.8558
	2	-101.02 (-572.144 to 371.709)	0.6769	-80.06 (-536.358 to 377.753)	0.7327
	3	-	-	-	-
	4	243.84 (-167.740 to 657.359)	0.2486	210.68 (-188.796 to 611.903)	0.3031
	5	214.02 (-277.208 to 706.511)	0.3947	172.40 (-304.647 to 650.594)	0.4789
Material Deprivation	1	282.39 (-277.632 to 846.684)	0.3268	221.95 (-321.158 to 768.999)	0.4258
	2	213.04 (-203.177 to 627.744)	0.3187	251.29 (-152.412 to 653.588)	0.2244
	3	-	-	-	-
	4	413.87 (-26.565 to 854.920)	0.0660	498.03 (70.395 to 926.243)	0.0224*
	5	326.01 (-136.827 to 785.715)	0.1655	387.85 (-61.093 to 833.895)	0.0884
Dependency	1	269.25 (-1,347.796 to 2,058.286)	0.7539	128.49 (-1428.844 to 1845.134)	0.8764
	2	2.75 (-457.554 to 464.904)	0.9908	-0.82 (-448.248 to 448.323)	0.9972
	3	-	-	-	-
	4	97.03 (-253.453 to 444.944)	0.5865	99.17 (-240.791 to 436.758)	0.5657
	5	178.04 (-246.143 to 602.952)	0.4113	205.17 (-206.379 to 617.403)	0.3280
Ethnic Concentration	1	102.44 (-342.392 to 545.144)	0.6519	95.37 (-335.689 to 524.443)	0.6642
	2	73.25 (-327.00 to 471.343)	0.7206	49.54 (-338.512 to 435.569)	0.8026
	3	-	-	-	-
	4	-29.26 (-477.633 to 420.811)	0.8988	-18.74 (-453.279 to 417.349)	0.9329
	5	-321.84 (-1,080.246 to 458.141)	0.4126	-372.65 (-1,107.426 to 382.153)	0.3264
Diabetes		3.22 (-257.396 to 264.778)	0.9808	40.80 (-212.036 to 294.508)	0.7524
Hypertension		298.29 (-65.908 to 657.341)	0.1053	301.36 (-51.812 to 649.753)	0.0909
Hyperlipidemia		-46.52 (-399.728 to 301.991)	0.7947	-83.95 (-426.562 to 254.297)	0.6276
Peripheral Vascular Disease		94.29 (-297.922 to 493.976)	0.6396	81.77 (-297.845 to 468.246)	0.6745
Cerebrovascular Disease		-161.78 (-591.139 to 277.216)	0.4662	-172.22 (-587.626 to 252.063)	0.4222
Chronic Obstructive Pulmonary Disease		250.59 (-102.013 to 609.387)	0.1678	270.00 (-71.440 to 617.156)	0.1243
History of Cancer		42.69 (-1,228.906 to 1,425.892)	0.9499	77.84 (-1,145.958 to 1,404.808)	0.9054
Dementia		3,246.92 (627.192 to 6,149.922)	0.0133*	2,624.76 (170.450 to 5,334.278)	0.0346*
History of Dialysis		956.51 (123.664 to 1,834.192)	0.0247*	856.71 (51.998 to 1,702.461)	0.0374*

Ischemic Heart Disease		-485.42 (-822.125 to -146.753)	0.0053*	-279.40 (-608.061 to 51.059)	0.0990
Heart Failure		716.51 (75.731 to 1,378.791)	0.0288*	434.83 (-175.734 to 1,064.989)	0.1667
Obesity		60.04 (-196.215 to 316.999)	0.6479	93.94 (-154.911 to 343.436)	0.4606
CCS Class	0	-	-	-	-
	1	-404.15 (-1,031.721 to 217.849)	0.2061	-401.75(-1,011.269 to 202.588)	0.1945
	2	-445.28 (-990.797 to 86.918)	0.1065	-463.32 (-922.869 to 53.800)	0.0829
	3	-456.72 (-1,011.309 to 85.347)	0.1038	-449.50 (-987.815 to 77.135)	0.0982
	4	-1,103.42 (-1,706.575 to -510.548)	0.0003*	-691.37 (-1,280.521 to -111.640)	0.0207*
NYHA	0	-	-	-	-
	1	59.67 (-218.453 to 338.292)	0.6754	61.77 (-207.883 to 331.903)	0.6542
	2	280.20 (-95.099 to 660.087)	0.1476	281.81 (-82.453 to 650.354)	0.1325
	3	150.69 (-328.687 to 640.414)	0.5433	200.97 (-264.448 to 675.965)	0.4023
	4	1,028.52 (-282.398 to 2,442.939)	0.1321	635.36 (-612.706 to 1,978.266)	0.3320
Previous CABG		-753.06 (-2,047.163 to 651.860)	0.2713	-812.59 (-2,075.991 to 554.137)	0.2222
Had Minor Complications		769.38 (291.353 to 1,256.916)	0.0015*	818.70 (363.385 to 1,282.617)	0.0004*
Had Moderate Complications		186.82 (-208.644 to 588.853)	0.3527	354.39 (-25.558 to 740.142)	0.0681
Had Major Complications		3,215.15 (2,004.462 to 4,487.217)	<0.0001*	3,015.09 (1,874.321 to 4,212.100)	<0.0001*
Use of Heart-Lung Machine		-715.07 (-1,251.384 o -193.127)	0.0086*	-503.28 (-1,027.604 to 7.615)	0.0572
ECMO		92,747.51 (58,196.726 to 138,579.655)	<0.0001*	83,271.87 (51,034.368 to 125,904.619)	<0.0001*
Robotic		923.32 (230.806 to 1,619.908)	0.0098*	540.37 (-139.664 to 1,223.619)	0.1212
Procedure Duration		23.21 (20.478 to 25.946)	<0.0001*	23.79 (21.148 to 26.451)	<0.0001*
Blood Product Transfusion		466.23 (110.333 to 826.126)	0.0102*	523.02 (180.424 to 869.215)	0.0028*
Albumin Transfusion		1,322.97 (951.349 to 1,700.025)	<0.0001*	1,309.53 (952.105 to 1,671.925)	<0.0001*
Length of Stay		1,467.82 (1,419.350 to 1,516.651)	<0.0001*	1,140.22 (1,067.903 to 1,212.842)	<0.0001*
More than One Special Care Unit		4,270.05 (3,730.316 to 4,818.374)	<0.0001*	4,290.25 (3,775.565 to 4,812.766)	<0.0001*
Return to Operating Room		5,768.44 (3,875.210 to 7,797.788)	<0.0001*	5,093.33 (3,297.286 to 7,014.798)	<0.0001*
Discharge Disposition	Home	-	-	-	-
	Died	19,027.38 (15,539.608 to 22,780.239)	<0.0001*	17,980.76 (14,675.952 to 21,527.948)	<0.0001*
	LAMA	-507.22 (-3,933.930 to 3,804.729)	0.7953	96.54 (-3,206.140 to 4,216.204)	0.9591
	Transfer	2,067.46 (1,098.224 to 3,076.187)	<0.0001*	1,942.78 (1,030.502 to 2,891.064)	<0.0001*
Fiscal Year	2015	-	-	-	-
	2016	-1,247.76 (-1,645.260 to -851.599)	<0.0001*	-1,285.98 (-1,671.608 to -901.610)	<0.0001*
	2017	-764.30 (-1,159.492 to -370.510)	0.0002*	-811.08 (-1,194.048 to -429.450)	<0.0001*
	2018	-1,689.94 (-2,085.426 to -1,295.827)	<0.0001*	-1,795.81 (-2,179.961 to -1,412.950)	<0.0001*
	2019	-572.87 (-98.708 to -160.642)	0.0066*	-687.41 (-1,088.459 to -286.962)	0.0008*
Length of Stay:Long Stay Indicator		-	-	590.08 (488.838 to 691.539)	<0.0001*

*: statistically significant

4.4.2 Model Diagnostics and Variance Inflation Factor

In order to assess multicollinearity, the variance inflation factor was found for the full specification of variables and tabulated in Table 7. A variance inflation factor of greater than or equal to 10 usually indicates problematic multicollinearity.[78] The variance inflation factor values demonstrate no problematic multicollinearity.

The Akaike information criterion (AIC) was found for each model and are tabulated in Table 8. Models 1 to 3 had comparable AIC values showing only marginal improvement in model fit. Inclusion of post-operative factors greatly improves model fit. Model 5 did not show any improvement in model fit.

Table 7: Variance Inflation Factor for Full Model Specification (Model 5)

	GVIF	$GVIF^{-2*Df}$	Df
Age	1.23	1.11	1
Sex	1.09	1.04	1
Instability	4.83	1.22	4
Material Deprivation	6.27	1.26	4
Dependency	2.26	1.11	4
Ethnic Concentration	2.92	1.14	4
Diabetes	1.14	1.07	1
Hypertension	1.18	1.09	1
Hyperlipidemia	1.17	1.08	1
Peripheral Vascular Disease	1.10	1.05	1
Cerebrovascular Disease	1.11	1.06	1
Chronic Obstructive Pulmonary Disease	1.05	1.02	1
History of Cancer	1.02	1.01	1
Dementia	1.09	1.04	1
History of Dialysis	1.04	1.02	1
Ischemic Heart Disease	1.78	1.34	1
Heart Failure	1.11	1.05	1
Obesity	1.14	1.07	1
CCS Class	2.24	1.11	4
NYHA	1.25	1.03	4
Previous CABG	1.06	1.03	1
Had Minor Complications	1.19	1.09	1
Had Moderate Complications	1.19	1.09	1
Had Major Complications	1.19	1.09	1
Use of Heart-Lung Machine	1.96	1.40	1
ECMO	1.01	1.00	1
Robotic	1.99	1.41	1
Procedure Duration	1.22	1.10	1

Blood Product Transfusion	1.30	1.14	1
Albumin Transfusion	1.16	1.08	1
Length of Stay	4.08	2.02	1
More than One Special Care Unit	1.24	1.11	1
Return to Operating Room	1.08	1.04	1
Discharge Disposition	1.25	1.04	3
Fiscal Year	1.15	1.02	4
Length of Stay:Long Stay Indicator	2.73	1.65	1

Table 8: Akaike Information Criterion for Nested Descriptive Models

	AIC
Model 1	67,736.22
Model 2	67,722.54
Model 3	66,309.00
Model 4	62,272.10
Model 5	62,127.26

4.5 Mediation Analysis

Baseline demographics, socio-economic variables, pre-operative patient characteristics, peri-operative variables, and post-operative factors are related by a complex network of pathways. Given this, complex causal mediation analyses are required to appropriately understand the effects of these variables on the cost of CABG procedures. Here we present mediation of the impact of peri-operative variables and select pre-discharge post-operative variables on total cost through length of stay. The variables assessed for mediation were use of heart-lung machine, robotic surgery, blood product transfusion, albumin transfusion, having had minor complications, having had moderate complications, having had major complications, return to the operating room, and requiring more than one special care unit. Length of stay was chosen as the mediating variable due to its strong correlation with total costs. Mediation analysis sheds light on whether peri-operative and pre-discharge variables increase cost just by increasing length of stay or induce other costs.

Robotic surgery decreased length of stay by an average of 1.7 days (95% confidence interval: -2.28 to -1.14 days) resulting in an average mediated effect of $-2,361.80 (95% confidence interval: $-3,176.220 to $-1,651.900). Robotic surgery has a direct effect of $771.24 (95% confidence interval: $55.830 to $1,459.300) resulting in a total effect of $-1,590.56 (95% confidence interval: $-2,615.810 to $-577.720). Blood product transfusion, albumin transfusion, having minor, moderate, and/or major complications, return to the operating room, and having required more than one special care unit all increase length of stay and thus have total effects on cost greater than their respective direct effects. In particular, return to the operating room increase length of stay by an average of 3.2 days (95% confidence interval: 1.37 to 5.40 days) which results in an average mediated effect of $4,969.63 (95% confidence interval: $-1,073.56 to $10,622.640). The direct effect of returning to the operating room on total costs was $6,351.38 (95% confidence interval: $3,878.030 to $8,574.220) resulting in a total effect of $11,321.01 (95% confidence interval: $5,600.481 to $17,028.200). A full list of results can be found in Table 9.

Table 9: Mediation of Select Variables on Total Cost through Length of Stay

	ΔLoS (days) (95% CI)	Average Mediated Effect ($) (95% CI)	Average Direct Effect ($) (95% CI)	Total Effect ($) (95% CI)
Use of Heart-Lung Machine	-0.1 (-0.60 to 0.39)	-137.10 (-820.483 to 496.630)	-613.89 (-1,156.231 to 76.300)	-750.99 (-1,665.646 to 183.220)
Use of Surgical Robot	-1.7 (-2.28 to -1.14)*	-2,361.80 (-3,176.220 to -1,651.900)*	771.24 (55.830 to 1,459.300)*	-1,590.56 (-2,615.810 to -577.720)*
Blood Product Transfusion	1.0 (0.65 to 1.33)*	1,350.21 (819.101 to 1,802.500)*	442.00 (134.890 to 782.200)*	1,792.21 (1,268.173 to 2,373.380)*
Albumin Transfusion	0.65 (0.31 to 1.01)*	878.47 (503.922 to 1,295.250)*	1,341.63 (973.746 to 1,682.530)*	2,220.10 (1,679.380 to 2,691.940)*
Had Minor Complication	2.2 (1.70 to 2.70)*	3,074.44 (2,463.805 to 3,844.050)*	715.83 (198.770 to 1,260.990)*	3,790.27 (3,039.529 to 4,610.980)*

Had Moderate Complication	2.2 (1.81 to 2.64)*	3,077.98 (2,471.422 to 3,663.470)*	197.09 (-175.749 to 543.860)	3,275.07 (2,567.465 to 3,990.890)*
Had Major Complication	2.0 (0.98 to 3.23)*	2,780.49 (881.232 to 4,455.450)*	3,095.15 (1,776.882 to 4,862.050)*	5,875.63 (3,525.924 to 8,047.940)*
Return to Operating Room	3.2 (1.37 to 5.40)*	4,969.63 (-1,073.56 to 10,622.640)	6,351.38 (3,878.030 to 8,574.220)*	11,321.01 (5,600.481 to 17,028.200)*
More than One Special Care Unit	2.9 (2.36 to 3.42)*	4,024.33 (3,313.284 to 4,836.790)*	4,197.96 (3,749.214 to 4,714.940)*	8,222.28 (7,345.040 to 9,269.830)*

*: statistically significant

4.6 Comparison of Estimative Models

The bias and mean relative squared error for each estimative model, as calculated using the validation data set, is shown in Table 10. Each of the estimative models tended to underestimate the total cost on average, though by only a marginal amount. Model 4, which used all variables except an interaction term with a long stay indicator, had the greatest bias while model 2, which only considered baseline characteristics and socio-economic variables, had the least bias. The amount of bias presented by each model varies only by a small amount (bias values range from $-32.23 to $-289.70) thus we conclude that the models are comparable with regards to accuracy. Model 1 had the highest mean relative squared error while model 5 had the least. Compared to model 4, model 5 showed marginal improvements in both accuracy and precision. Therefore, inclusion of all baseline patient characteristic, peri-operative, and post-operative factors as well as an interaction term between length of stay and a long stay indicator provides the most accurate and precise estimation of total CABG cost.

Table 10: Bias and Mean Relative Squared Error of Prediction Models

	Bias ($)	MRSE
Model 1	-100.07	4,681.94
Model 2	-32.23	4,652.34
Model 3	-203.05	4,101.43
Model 4	-289.70	1,430.86
Model 5	-120.91	1,269.07

Chapter 5

5 Discussion

5.1 Overview of Results and Implications

The goal of this thesis was to explore the determinants of the cost of CABG procedures at the LHSC to inform clinical and health policy decision-makers. The determinants of cost are explored through three main analyses: i) selection of the appropriate statistical model for regression analysis of total cost, ii) descriptive analysis to identify the factors that are significantly associated with variation in total cost, with variables categorized into patient socio-demographics, pre-operative patient characteristics, peri-operative factors, and post-operative factors, and iii) exploring mediation of the impact of peri-operative factors on costs through length of stay. Estimative models with the aforementioned variable categorization were developed to facilitate comparison to the funding models that are currently used to inform reimbursement decisions. These analyses yielded four key findings.

First, relationships between pre-operative patient characteristics, socio-demographic factors, peri-operative factors, and post-operative factors are quite complex but are important to investigate to truly understand their impacts on costs. Model 1, which only considered basic patient demographic information as well as pre-operative patient characteristics, showed that the presence of co-morbid conditions upon admission apart from diabetes, hypertension and hyperlipidemia were associated with an increase in total costs. Having had dementia upon admission was associated with the largest increase in costs of $33,324. These relationships did not change when adjusting for socio-demographic factors in addition to the baseline patient characteristics as seen in model 2. Model 3, in which peri-operative variables are considered in addition to the variables previous models adjust for, shows reduction in the strength of the association between baseline characteristics and cost. Several variables are found to no longer be statistically significant such as peripheral vascular disease and cerebrovascular disease. Other variables have diminished impact on cost – the largest of which is found with presence of dementia upon admission ($33,363 in model 2 to $19,226 in model 3; a reduction of $14,137). These impacts are further reduced when post-operative factors are also adjusted for. For example, the impact of dementia becomes further reduced to $3,247 (a reduction of $15,979). This progressive decrease of cost impacts indicates that the relationship of upstream variables (variables that are determined earlier in a patient stay) have a complex relationship with – and are mediated by – downstream variables (variables that are determined relatively later in a patient stay). Baseline characteristics are mediated by both peri-operative and post-operative factors whereas peri-operative variables are mediated by post-operative factors.

Second, upstream variables are mediated by downstream variables, thus causal mediation analyses can reveal very important insights for costs. Model 2, which considers ecological socio-economic demographics in addition to adjustment of baseline patient characteristics, showed that living in FSA's that are associated with higher instability quintiles was found to be associated with higher total costs when compared to living in FSA's that are associated with the median quintile. A similar pattern was found for the dependency measure. However, the highest quintile was not found to be associated with a significant increase in cost compared with the median quintile. Material deprivation and ethnic concentration measures were found not to have any statistically significant association with costs. SES factors are no longer significant when peri-operative and post-operative factors are added to the regression model. However, this does not mean that SES does not play a role in costs. Chi-squared tests between the socio-demographic variables and co-morbid conditions reveals that the association between socio-demographics and cost is more complex than the analysis results show (full table of p-values shown in Appendix E). Mediation analyses of the impact of peri-operative factors on costs through length of stay provide further evidence that the complexity that belies the relationships between upstream and downstream variables, and total costs. For example, recall that robotic surgery was associated with a direct increase in costs of $771 but also a decreased length of stay of 1.7 days (which was associated with a decrease in costs of $2,361). This has implications that investment in robotic surgery may be worthwhile due to improvements in recovery time.

Third, HIG methodology which determines reimbursement rates may not capture important variation in costs. The current reimbursement of CABG procedures at the LHSC are informed by funding models based on the HIG weight assigned for each case. The HIG methodology takes into consideration seven factors to calculate the HIG weight: age, flagged intervention (FI), intervention event (IE), out-of-hospital (OOH) intervention, special care unit (SCU), discharged to home care, and maternal age ≥ 40. Our best fitting estimative model includes many variables that are not considered by the HIG methodology including important co-morbidities like dementia and peri-operative factors such as major complications during surgery. It could be argued that taking length of stay into consideration may justify not adjusting for these variables. However, we show that this is not sufficient because these variables have direct impacts on costs beyond the influence on length of stay.

Finally, the results demonstrate the importance of careful selection of regression models. We performed model selection with 10-fold cross-validation using the mean relative squared error as the optimization criterion. We found that no matter the distribution family used, the identity-link performed better than the log-link in terms of precision. Additionally, the identity-link provides for much easier interpretation of results because they require no transformation and are additive.

This is important when discussing results with decision makers. In cost regression analyses in the published literature, researchers sometimes do not test the fit of GLM models with identity link.[79,80] Our results suggest that the Gamma GLM with identity-link should be considered more often than it currently is.

5.2 Comparison of Results to Existing Literature

5.2.1 Descriptive Analyses

We found that our cohort of CABG patients at the LHSC was very similar to the patient populations of other studies looking at the cost or cost-effectiveness of CABG. The proportion of co-morbidities present upon admission were quite similar. For example, 40.6% of patients had diabetes upon admission. This was found to be very similar to the proportion of patients with diabetes upon admission in several other cost or cost-effectiveness analyses of CABG (range: 24.8 – 40%).[29,30,81] Thus, the results found here may be quite generalizable to other patient populations despite the localized data.

There were only two studies that we had identified that analyzed the cost of CABG surgery in the Canadian context. Naglie et al. performed an analysis of direct CABG costs for a sample of CABG patients from a tertiary care university-affiliated hospital in Toronto, Ontario, Canada.[30] The study sample was limited to patients with triple-vessel or left main coronary artery disease with no previous history of CABG who underwent CABG surgery without concomitant valve procedure between April 1st, 1991 and March 31st, 1992. They found that age, complications, and ejection fraction were statistically significant factors contributing to the direct cost of CABG surgery.[30] In this study, age was dichotomized. Patients were considered ‘older’ if they were aged 65 years or more, and ‘younger’ otherwise. Complications were dichotomized as ‘yes’ if there were any complications and ‘no’ otherwise.[30] Ejection fraction was dichotomized as

‘<40%’ if the left ventricular ejection fraction was less than 40% and ‘≥ 40%’ otherwise. Naglie et al. included several pre-operative patient characteristics such as sex and presence of diabetes, but did not find these to be statistically significant.[30] Our results mostly agree with this study. We compare results from Model 3, which adjusts for baseline patient characteristics, socio-demographics, and peri-operative variables, because it is most comparable to the risk-adjustment variables included in the analysis by Naglie et al. Congruent with Naglie et al., we found that diabetes was not statistically significantly associated with a change in costs. We also found that complications were associated with increased costs, though we considered minor, moderate, and major complications separately. We did not include left ventricular ejection fraction because of its high correlation with CCS class and because it was not collected for only 10% of the study cohort.

Austin et al. used administrative hospital discharge data from the Calgary Regional Health Authority.[31] The data pertained to patients admitted for CABG surgery at a hospital in Calgary, Alberta, Canada from June 1994 to March 1998. Patient age and sex were considered as well as several comorbidities. Austin et al. found several variables to be associated with increased costs including age, female sex, CVD, and congestive heart failure.[31] Since Austin et al. do not consider any peri- or post-operative factors, we can only compare the results from Model 1, which included demographics and pre-operative patient characteristics. Contrary to both Naglie et al. and our results, diabetes mellitus was found to be associated with a decrease in costs. However, these differences may be due to Austin et al. adjusting for diabetes mellitus and diabetes with complications separately. There are several other discrepancies between our results and those presented by Austin et al. For example, Model 1 showed that PVD and COPD were associated with increased costs. Austin et al. did not find these comorbidities to be statistically significant. It is difficult to determine the reason for these discrepancies. The discrepancies may be due to differences in the study cohort. Our study only considers patients who underwent elective CABG without concomitant valve surgery whereas Austin et al. considers all CABG patients.[31]

5.2.2 Socio-economic Status

We did not find studies related to the relationship between socio-economic status and CABG costs. However, it is well-known that socio-economic status has a complex relationship with health status and healthcare costs.[57,58,65,68] Roos et al. found that for people in Winnipeg, the relative affluence of the neighbourhood where a given patient lives is significantly associated with rates of premature death and total healthcare expenditure.[57] Less wealthy neighbourhoods were associated with 37% more premature deaths and 15% more total expenditures than the wealthiest neighbourhoods. Similarly, Thavorn et al. found that lower income was associated with higher healthcare costs.[68] Thavorn et al. also found that living in areas of higher deprivation, instability, ethnic concentration, and/or dependency were associated with higher healthcare costs. Other studies found that higher SES patients had lower end-of-life expenditures – adjusting for comorbidities – and higher income and education was associated with lower risk of cardiovascular death or myocardial infarction.[58,65]

Our descriptive analyses showed important univariate associations between socio-demographic variables – instability, material deprivation, dependency, and ethnic concentration – and CABG costs. These associations diminish when adjusting for other variables indicating the complexity of these relationships. Due to the potential for ecological fallacy we decided not to conduct formal mediation analyses for these variables. We acknowledge that the use of ecological measures of SES introduces a large amount of measurement error and the aggregation of scores can hide heterogeneity. However, we do demonstrate that several of the ecological socio-economic variables are correlated with the presence of some co-morbidities upon admission. For example, we found that the instability quintile of the forward sortation area where a patient lives was correlated with ischemic heart disease and history of heart failure (a full list of p-values shown in Appendix E). Future studies should explore these relationships further with socio-economic data collected at the patient level with the aim to uncover the complex relationships between socio-economic status, health status, and CABG costs.

5.2.3 Mediation Analyses

The results of our mediation analysis highlight the complexity of the relationships between patient characteristics, peri- and post-operative factors, and costs. Of particular interest is the association of robotic CABG surgery with direct and indirect changes in costs. A study by Leyvi et al. performed a multivariate logistic regression analysis and found that patients who underwent robotic CABG had lower rates of post-operative complications and shorter length of stay.[82] This is congruent with what we found in our analyses.

5.3 Strengths and Limitations

There are many strengths to the work that is presented in this thesis. First and foremost, the analyses incorporate data from several key domains relevant to the study of hospital costs. The thesis explores methodological considerations in cost analysis, performs causal mediation analysis to illuminate some of the complexities in the relationships between peri-operative factors and total costs, and develops models for the estimation of costs in addition to identifying the main factors that are significantly associated with total costs. However, it is not without its limitations.

One limitation of this study is the use of ecological measures for socio-economic status. There are many problems that arise when using ecological measures to estimate individual level costs. Although we are very careful with the interpretation of the results, there is always a possibility of ecological fallacy. For example, an individual may live in a forward sortation area associated with high material deprivation – which is related to income – but this may not reflect the deprivation of that individual. To avoid this potential ecological fallacy, it is important to collect this socio-economic data at the patient level for future work.

A second limitation is that we were unable to explore interaction terms outside of the interaction between length of stay and long stay indicator. These interaction terms were not included because they were not within the scope of this thesis study. However, these interaction terms are quite important to explore to truly understand how and why the various patient characteristics and in-hospital factors are impacting total cost. Yu et al. showed that SES is an important effect modifier of the relationship between multimorbidity and healthcare cost. This may be one such interaction that should be included in future work to account for possible effect modification of the impact of co-morbid conditions on CABG costs by SES.

The retrospective nature of the study is an additional limitation due to the reliance of secondary datasets. Variables may be incorrectly specified due to errors of omission (i.e. information was not recorded). There are also several limitations due to sample size. Though the overall sample size was sufficiently large, there were several limitations in our ability to investigate certain factors such as those who had 'left against medical advice'. It is important to note that despite evidence of similar patient populations to others reported in the literature, our findings identifying cost drivers may not always be generalizable to other institutions. However, our goal was to provide information on the cost drivers specifically for LHSC. Therefore, the data were appropriate for this purpose.

5.4 Future Work

The key findings of this thesis have important implications for the analysis of hospital costs as well as for potential impacts in clinical practice. Our descriptive analyses demonstrate the complexity underlying the relationships between pre-operative patient characteristics, socio-demographic factors, peri-operative and post-operative factors, and costs. Future work should further explore these relationships. One way to do this is to include interaction terms to explore potential effect modification. An example of potential effect modification to be explore is the modification of the association between multimorbidity and costs through socio-demographic factors as demonstrated by Thavorn et al.[68]

Mediation analyses are another way to further explore the complex relationships between amongst variables. We demonstrate this by investigating the mediation of the impact of peri-operative factors on costs through length of stay. Other important mediation analyses that would be important to explore are mediation of the impact of co-morbid conditions present upon admission on costs through peri-operative factors such as procedure duration or complications. Our analyses found that the impact of dementia, a co-morbid conditions, on costs diminished when adjusting for peri-operative factors – in particular dementia. Understanding the mechanism behind how dementia – and other co-morbid conditions – are impacting total costs is important for improvement of clinical practices as well as reduction of costs.

Future work should also explore the relationships between patient level socio-economic status and CABG costs. As previously mentioned, there it is well-known that socio-economic status has complex relationships with health status and healthcare costs. However, we did not find any studies that investigated the relationship between SES and CABG costs. Future work should aim to investigate this relationship further.

5.5 Conclusion

This thesis analyzes multiple different domains in order to understand the significant factors that impact the cost of CABG procedure at the LHSC through model selection, construction of nested descriptive models, exploration of mediation analysis of the impact of peri-operative factors and cost through length of stay, and construction of estimative models.

The work presented here highlights the immensely complex story that underlies the relationships between patient characteristics, socio-demographics, peri-operative and post-operative clinical factors, and CABG costs. At other Ontario cardiac surgical centres different factors may drive costs. However, the approach we outline here can be used to identify cost drivers at other cardiac surgical centres or can be applied to understand cost drivers for all cardiac surgical patients in Ontario.

References

1. Canadian Institute for Health Information. National Health Expenditure Trends, 1975 to 2019. https://www.cihi.ca/en/national-health-expenditure-trends-1975-to-2019. Published 2019.

2. Ontario C. *Report on Adult Cardiac Surgery: Isolated Coronary Artery Bypass Graft (CABG) Surgery, Isolated Aortic Valve Replacement (AVR) Surgery and Combined CABG and AVR Surgery October 2011 - March 2016*.; 2018.

3. Coronary artery disease | Heart and Stroke Foundation. Heart and Stroke Foundation of Canada. doi:10.1364/JOSA.65.000542

4. Willerson David R Holmes JT, Editors J. *Coronary Artery Disease*. http://www.springer.com/series/10474. Accessed November 21, 2019.

5. Atherosclerosis | National Heart, Lung, and Blood Institute (NHLBI). https://www.nhlbi.nih.gov/health-topics/atherosclerosis. Accessed November 21, 2019.

6. Public Health Agency of Canada. *Report from the Canadian Chronic Disease Surveillance System: Heart Disease in Canada, 2018*.; 2018. https://www.canada.ca/content/dam/phac-aspc/documents/services/publications/diseases-conditions/report-heart-disease-canada-2018/pub1-eng.pdf (Archived by WebCite® at http://www.webcitation.org/75UuX4oGO)%0Ahttps://www.canada.ca/content/dam/phac-aspc/docu. Accessed November 21, 2019.

7. Health Ontario P. *The Burden of Chronic Diseases in Ontario*.; 2019.

8. Barrett-Connor EL. Obesity, atherosclerosis, and coronary artery disease. *Ann Intern Med*. 1985;103(6 II):1010-1019. doi:10.7326/0003-4819-103-6-1010

9. Wilson PWF. Established Risk Factors and Coronary Artery Disease: The Framingham Study. *Am J Hypertens*. 1994;7(7_Pt_2):7S-12S. doi:10.1093/ajh/7.7.7S

10. Mancini GBJ, Gosselin G, Chow B, et al. Canadian Cardiovascular Society Guidelines for the diagnosis and management of stable ischemic heart disease. *Can J Cardiol*. 2014;30(8):837-849. doi:10.1016/j.cjca.2014.05.013

11. Mancini GBJ, Gosselin G, Chow B, et al. Canadian Cardiovascular Society Guidelines for the diagnosis and management of stable ischemic heart disease. *Can J Cardiol*. 2014;30(8):837-849. doi:10.1016/j.cjca.2014.05.013

12. Teo KK, Cohen E, Buller C, et al. Canadian Cardiovascular Society/Canadian Association ofInterventional Cardiology/Canadian Society of CardiacSurgery Position Statement on Revascularization-Multivessel Coronary Artery Disease. *Can J Cardiol*. 2014;30(12):1482-1491. doi:10.1016/j.cjca.2014.09.034

13. Braun MM, Stevens WA, Barstow CH. Stable Coronary Artery Disease: Treatment. *Am Fam Physician*. 2018;97(6):376-384.

14. Holmes DR. Percutaneous Coronary Intervention and the Various Coronary Artery Disease Syndromes. In: *Coronary Artery Disease*. Springer Verlag; 2015:597-620. doi:https://doi-org.proxy1.lib.uwo.ca/10.1007/978-1-4471-2828-1

15. Hachamovitch R, Hayes SW, Friedman JD, Cohen I, Berman DS. Comparison of the short-term survival benefit associated with revascularization compared with medical therapy in patients with no prior coronary artery disease undergoing stress myocardial perfusion single photon emission

computed tomography. *Circulation*. 2003;107(23):2900-2906. doi:10.1161/01.CIR.0000072790.23090.41

16. Shaw LJ, Berman DS, Maron DJ, et al. Optimal medical therapy with or without percutaneous coronary intervention to reduce ischemic burden: results from the Clinical Outcomes Utilizing Revascularization and Aggressive Drug Evaluation (COURAGE) trial nuclear substudy. *Circulation*. 2008;117(10):1283-1291. doi:10.1161/CIRCULATIONAHA.107.743963

17. Shaw LJ, Weintraub WS, Maron DJ, et al. Baseline stress myocardial perfusion imaging results and outcomes in patients with stable ischemic heart disease randomized to optimal medical therapy with or without percutaneous coronary intervention. *Am Heart J*. 2012;164(2):243-250. doi:10.1016/j.ahj.2012.05.018

18. Murashita T. The Choice of Graft Conduits in Coronary Artery Bypass Grafting. In: Aronow WS, ed. *Coronary Artery Bypass Graft Surgery*. IntechOpen; 2017. doi:http://dx.doi.org/10.5772/intechopen.70398

19. Wilson JM. Coronary Artery Bypass Surgery and Percutaneous Coronary Revascularization: Impact on Morbidity and Mortality in Patients with Coronary Artery Disease. In: *Coronary Artery Disease*. Springer Verlag; 2015:683-726. doi:https://doi-org.proxy1.lib.uwo.ca/10.1007/978-1-4471-2828-1

20. Horneffer PJ, Gardner TJ, Manolio TA, et al. The effects of age on outcome after coronary bypass surgery. *Circulation*. 1987;76(5 Pt 2):V6-12.

21. Ascione R, Rees K, Santo K, et al. Coronary artery bypass grafting in patients over 70 years old: the influence of age and surgical technique on early and mid-term clinical outcomes. *Eur J cardio-thoracic Surg Off J Eur Assoc Cardio-thoracic Surg*. 2002;22(1):124-128. doi:10.1016/s1010-7940(02)00243-9

22. Farkouh ME, Domanski M, Sleeper LA, et al. Strategies for Multivessel Revascularization in Patients with Diabetes. *N Engl J Med*. 2012;367(25):2375-2384. doi:10.1056/NEJMoa1211585

23. Farkouh ME, Fuster V, Cohen DJ, Trial F. Quality of Life After PCI vs CABG Among Patients With Diabetes and Multivessel Coronary Artery Disease A Randomized Clinical Trial. 2020;64111(15):1581-1590. doi:10.1001/jama.2013.279208

24. Serruys PW, Morice M-C, Kappetein AP, et al. Percutaneous Coronary Intervention versus Coronary-Artery Bypass Grafting for Severe Coronary Artery Disease. *N Engl J Med*. 2009;360(10):961-972. doi:10.1056/NEJMoa0804626

25. Hlatky MA, Boothroyd DB, Bravata DM, et al. Coronary artery bypass surgery compared with percutaneous coronary interventions for multivessel disease: a collaborative analysis of individual patient data from ten randomised trials. *Lancet (London, England)*. 2009;373(9670):1190-1197. doi:10.1016/S0140-6736(09)60552-3

26. Tu B, Rich B, Labos C, Brophy JM. Coronary revascularization in diabetic patients: A systematic review and bayesian network meta-analysis. *Ann Intern Med*. 2014;161(10):724-732. doi:10.7326/M14-0808

27. Oakes G. *Report on Adult Cardiac Surgery: Isolated Coronary Artery Bypass Graft (CABG) Surgery, Isolated Aortic Valve Replacement (AVR) Surgery and Combined CABG and AVR Surgery October 2011 - March 2016*.; 2018. https://www.corhealthontario.ca/Report-on-Adult-Cardiac-Surgery-October-2011-March-2016-April-2018.pdf.

28. Johnson A, Parlow J, Milne B, et al. Economies of scale: body mass index and costs of cardiac

surgery in Ontario, Canada. *Eur J Heal Econ*. 2017;18(4):471-479. doi:10.1007/s10198-016-0803-4

29. Goldfarb M, Bendayan M, Rudski LG, et al. Cost of Cardiac Surgery in Frail Compared With Nonfrail Older Adults. *Can J Cardiol*. 2017;33(8):1020-1026. doi:10.1016/j.cjca.2017.03.019

30. Naglie G, Tansey C, Krahn MD, O'Rourke K, Detsky AS, Bolley H. Direct costs of coronary artery bypass grafting in patients aged 65 years or more and those under age 65. *Cmaj*. 1999;160(6):805-811.

31. Austin PC, Ghali WA, Tu J V. A comparison of several regression models for analysing cost of CABG surgery. *Stat Med*. 2003;22(17):2799-2815. doi:10.1002/sim.1442

32. Wong DT, Cheng DCH, Kustra R, et al. Risk Factors of Delayed Extubation, Prolonged Length of Stay in the Intensive Care Unit, and Mortality in Patients Undergoing Coronary Artery Bypass Graft with Fast-track Cardiac Anesthesia : A New Cardiac Risk Score. *Anesthesiology*. 1999;91(4):936. doi:10.1097/00000542-199910000-00012

33. Cheng DCH, Wall C, Djaiani G, et al. Randomized Assessment of Resource Use in Fast-track Cardiac Surgery 1-Year after Hospital Discharge. *Anesthesiology*. 2003;98(3):651-657. doi:10.1097/00000542-200303000-00013

34. Cheng DCH, Karski J, Peniston C, et al. Morbidity outcome in early versus conventional tracheal extubation after coronary artery bypass grafting: A prospective randomized controlled trial. *J Thorac Cardiovasc Surg*. 1996;112(3):755-764. doi:10.1016/S0022-5223(96)70062-4

35. Cheng DCH, Karski J, Peniston C, et al. Early Tracheal Extubation after Coronary Artery Bypass Graft Surgery Reduces Costs and Improves Resource Use: A Prospective, Randomized, Controlled Trial. *Anesthesiology*. 1996;85(6):1300-1310. doi:10.1097/00000542-199612000-00011

36. Lamy A, Tong W, Devereaux PJ, et al. The cost implications of off-pump versus on-pump coronary artery bypass graft surgery at one year. *Ann Thorac Surg*. 2014;98(5):1620-1625. doi:10.1016/j.athoracsur.2014.06.046

37. Lamy A, Devereaux PJ, Prabhakaran D, et al. Effects of Off-Pump and On-Pump Coronary-Artery Bypass Grafting at 1 Year. *N Engl J Med*. 2013;368(13):1179-1188. doi:10.1056/NEJMoa1301228

38. Scudeler TL, Hueb WA, Farkouh ME, et al. Cost-effectiveness of on-pump and off-pump coronary artery bypass grafting for patients with coronary artery disease: Results from the MASS III trial. *Int J Cardiol*. 2018;273:63-68. doi:10.1016/j.ijcard.2018.08.044

39. Sutherland JM. *HOSPITAL PAYMENT MECHANISMS: AN OVERVIEW AND OPTIONS FOR CANADA*.; 2011.

40. Ontario Hospital Association. *Health System Funding Reform (HSFR): What You Need To Know*. https://www.oha.com/Documents/HSFR-What You Need To Know.pdf.

41. Ministry of Health and Long-term Care. *List of Quality-Based Procedures*. http://www.health.gov.on.ca/en/pro/programs/ecfa/docs/qbp_fiscal_list_en.pdf.

42. Ontario Hospital Association. *Quality-Based Procedures (QBP): What You Need To Know*. https://www.oha.com/Documents/QBP Overview Fact Sheet.pdf.

43. Ontario Hospital Association. *Toolkit to Support the Implementation of Quality-Based Procedures*. https://www.oha.com/Documents/QBP Toolkit.pdf.

44. Association OH. Health-Based Allocation Model (HBAM): What You Need To Know. 2012. https://drchrissimpson.com/2012/12/17/hbam-in-ontario-the-road-to-a-sustainable-more-efficient-health-care-system/.

45. CIHI. Assigning HIG Weights and ELOS Values to Ontario Inpatient DAD Cases 2015, Version 1.0. 2015;(January).

46. Canadian Institute for Health Information. *Canadian Patient Cost Database Technical Document: MIS Patient Costing Methodology*.; 2019. https://www.cihi.ca/sites/default/files/document/mis_patient_cost_meth_en_0.pdf.

47. Vittinghoff E, Glidden D V, Shiboski SC, McCulloch CE. *Regression Methods in Biostatistics: Linear, Logistic, Survival, and Repeated Measures Models*. Springer New York; 2012. https://books.google.ca/books?id=boMUM6N8V4wC.

48. Manning WG, Mullahy J. Estimating log models: To transform or not to transform? *J Health Econ*. 2001;20(4):461-494. doi:10.1016/S0167-6296(01)00086-8

49. Barber J, Thompson S. Multiple regression of cost data: Use of generalised linear models. *J Heal Serv Res Policy*. 2004;9(4):197-204. doi:10.1258/1355819042250249

50. Basu A, Manning WG, Polsky D. ESTIMATING TREATMENT EFFECTS ON HEALTHCARE COSTS UNDER EXOGENEITY: IS THERE A ‘MAGIC BULLET’? 2012:1-32. doi:10.1007/s10742-011-0072-8.ESTIMATING

51. Garrido MM, Deb P, Burgess JF, Penrod D. Choosing Models for Health Care Cost Analyses : Issues of Nonlinearity and Endogeneity. 2012:2377-2397. doi:10.1111/j.1475-6773.2012.01414.x

52. Duan N, Manning WG, Morris CN, Newhouse JP. A comparison of alternative models for the demand for medical care. *J Bus Econ Stat*. 1983;1(2):115-126. doi:10.1080/07350015.1983.10509330

53. Basu A, Manning WG. Issues for the Next Generation of Health Care Cost Analyses. *Med Care*. 2009;47(Supplement):S109-S114. doi:10.1097/mlr.0b013e31819c94a1

54. Basu A, Rathouz PJ. Estimating marginal and incremental effects on health outcomes using flexible link and variance function models. *Biostatistics*. 2005;6(1):93-109. doi:10.1093/biostatistics/kxh020

55. Asada Y, Kephart G. Equity in health services use and intensity of use in Canada. *BMC Health Serv Res*. 2007;7(1):41. doi:10.1186/1472-6963-7-41

56. Filc D, Davidovich N, Novack L, Balicer RD. Is socioeconomic status associated with utilization of health care services in a single-payer universal health care system? *Int J Equity Health*. 2014;13(1):115. doi:10.1186/s12939-014-0115-1

57. Roos NP, Sullivan K, Walld R, MacWilliam L. Potential savings from reducing inequalities in health. *Can J Public Heal*. 2004;95(6):460-464. doi:10.1007/bf03403994

58. Yu CW, Alavinia SM, Alter DA. Impact of socioeconomic status on end-of-life costs: A systematic review and meta-analysis. *BMC Palliat Care*. 2020;19(1):1-15. doi:10.1186/s12904-020-0538-y

59. Rao S V., Kaul P, Newby LK, et al. Poverty, process of care, and outcome in acute coronary syndromes. *J Am Coll Cardiol*. 2003;41(11):1948-1954. doi:10.1016/S0735-1097(03)00402-9

60. Alter DA, Naylor CD, Austin P, Tu J V. Effects of socioeconomic status on access to invasive

cardiac procedures and on mortality after acute myocardial infarction. *N Engl J Med*. 1999;341(18):1359-1367. doi:10.1056/NEJM199910283411806

61. Carlisle DM, Leake BD. Differences in the effect of patients' socioeconomic status on the use of invasive cardiovascular procedures across health insurance categories. *Am J Public Health*. 1998;88(7):1089-1092. doi:10.2105/AJPH.88.7.1089

62. Biswas S, Andrianopoulos N, Duffy SJ, et al. Impact of Socioeconomic Status on Clinical Outcomes in Patients With ST-Segment–Elevation Myocardial Infarction. *Circ Cardiovasc Qual Outcomes*. 2019;12(1). doi:10.1161/CIRCOUTCOMES.118.004979

63. Zommorodi S, Leander K, Roy J, Steuer J, Hultgren R. Understanding abdominal aortic aneurysm epidemiology: socioeconomic position affects outcome. *J Epidemiol Community Health*. 2018;72(10):904-910. doi:10.1136/jech-2018-210644

64. Medhekar AN, Adhikari S, Abdul-Al AS, et al. Lower socioeconomic status is associated with increased long-term mortality after sudden cardiac arrest. *Clin Cardiol*. June 2019:clc.23211. doi:10.1002/clc.23211

65. Shaw LJ, Merz CNB, Bittner V, et al. Importance of socioeconomic status as a predictor of cardiovascular outcome and costs of care in women with suspected myocardial ischemia. Results from the national institutes of health, national heart, lung and blood institute-sponsored Women's Ischemia . *J Women's Heal*. 2008;17(7):1081-1092. doi:10.1089/jwh.2007.0596

66. Matheson FI, van Ingen T. *2016 Ontario Marginalization Index User Guide*.; 2018. https://www.publichealthontario.ca/-/media/documents/o/2017/on-marg-userguide.pdf?la=en.

67. Matheson FI, Dunn JR, Smith KLW, Moineddin R, Glazier RH. Development of the Canadian Marginalization Index: A New Tool for the Study of Inequality. 2012;103:3-5.

68. Thavorn K, Maxwell CJ, Gruneir A, et al. Effect of socio-demographic factors on the association between multimorbidity and healthcare costs: a population-based, retrospective cohort study. *BMJ Open*. 2017;7(10):e017264. doi:10.1136/bmjopen-2017-017264

69. Buick JE, Ray JG, Kiss A, Morrison LJ. The association between neighborhood effects and out-of-hospital cardiac arrest outcomes. *Resuscitation*. 2016;103:14-19. doi:10.1016/j.resuscitation.2016.03.008

70. Buick JE, Allan KS, Ray JG, et al. Does location matter? A proposed methodology to evaluate neighbourhood effects on cardiac arrest survival and bystander CPR. *CJEM*. 2015;17(3):286-294. doi:10.1017/cem.2014.40

71. Inman M, Daneman D, Curtis J, et al. Social Determinants of Health Are Associated with Modifiable Risk Factors for Cardiovascular Disease and Vascular Function in Pediatric Type 1 Diabetes. *J Pediatr*. 2016;177:167-172. doi:10.1016/j.jpeds.2016.06.049

72. Moin JS, Moineddin R, Upshur REG. Measuring the association between marginalization and multimorbidity in Ontario, Canada: A cross-sectional study. *J Comorbidity*. 2018;8(1):2235042X18814939. doi:10.1177/2235042X18814939

73. Canadian Institute for Health Information. *Data Quality Documentation, Discharge Abstract Database—Multi-Year Information*. https://www.cihi.ca/sites/default/files/document/dad_multi-year_en.pdf.

74. Statistics Canada. Postal Code OM Conversion File Plus (PCCF+). https://www150.statcan.gc.ca/n1/en/catalogue/82F0086X.

75. Statistics Canada. Consumer Price Index, annual average, not seasonally adjusted. https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1810000501.

76. Jones PM, Cherry RA, Allen BN, et al. Association between handover of anesthesia care and adverse postoperative outcomes among patients undergoing major surgery. *JAMA - J Am Med Assoc*. 2018;319(2):143-153. doi:10.1001/jama.2017.20040

77. Davison AC, Hinkley D V. *Bootstrap Methods and Their Application*. Cambridge: Cambridge University Press; 1997. doi:DOI: 10.1017/CBO9780511802843

78. Black WC, Babin BJ, Anderson RE. *Multivariate Data Analysis*. Vol 5.

79. Moran JL, Solomon PJ, Peisach AR, Martin J. New models for old questions: generalized linear models for cost prediction. *J Eval Clin Pract*. 2007;13(3):381-389. doi:10.1111/j.1365-2753.2006.00711.x

80. Aljabbary T, Qiu F, Masih S, et al. Association of Clinical and Economic Outcomes With Permanent Pacemaker Implantation After Transcatheter Aortic Valve Replacement. *JAMA Netw Open*. 2018;1(1):e180088-e180088. doi:10.1001/jamanetworkopen.2018.0088

81. Zhang Z, Kolm P, Grau-Sepulveda M V., et al. Cost-effectiveness of revascularization strategies: The ASCERT study. *J Am Coll Cardiol*. 2015;65(1):1-11. doi:10.1016/j.jacc.2014.09.078

82. Leyvi G, Forest SJ, Srinivas VS, et al. Robotic coronary artery bypass grafting decreases 30-day complication rate, length of stay, and acute care facility discharge rate compared with conventional surgery. *Innovations (Phila)*. 2014;9(5):361-367; discussion 367. doi:10.1097/IMI.0000000000000095

Appendices

Appendix A: Data Dictionary

CABG Cost Study, Data Dictionary

Cohort Definition:

- Patients who have undergone elective CABG surgery as defined in the CIHI-DAD (Apr. 1, 2014 – March 31, 2019)
- Exclude patients who have also undergone any type of valve operation (TAVI, mitral valve, tricuspid valve, or any other valve procedure)

Preoperative Patient Characteristics			
Variable	Type/format	Source database	Description
Health Card Number	Number	Cerner	Used to link databases and identify duplicates, will be converted into a unique de-identified ID number
Hospital Number	Number	Cerner	
Date of Birth	MMDDYYYY	Cerner	Used to calculate age in days at time of pre-admission clinic visit
Sex	M/F/other	Cerner	
Visit/Encounter Number	Number	Cerner	Used to link databases
Forward Sortation Area	ANA	Cerner	
Height	Number	Cerner	
Weight	Number	Cerner	
Body Mass Index	Number	Calculated	Calculated from Height and Weight of Patient
Comorbiditi es		DAD	All comorbid diagnoses present upon admission (DXTYPE = 1)
Comorbidities of Interest			
Diabetes	Binary	DAD/Surginet	Diabetes mellitus • Check for diabetes diagnosis in CIHI-DAD on admission (DXTYPE = 1): • ICD-10: E10, E11, E13, E14 • Check Surginet for pre-admit clinical visit for history of diabetes
Hypertension	Binary	DAD/Surginet	Hypertension • Check for hypertension diagnosis in CIHI-DAD on admission (DXTYPE = 1): • ICD-10: I10-I13, I15

			• Check Surginet for pre-admit clinical visit for history of hypertension
Hyperlipidemia	Binary	DAD/Surginet	Hyperlipidemia Check for dyslipidemia diagnosis in CIHI-DAD on admission (DXTYPE = 1): • Diagnosis codes - ICD-9: 272 or ICD-10: E78 • Check Surginet for pre-admit clinical visit for history of hyperlipidemia or dyslipidemia
Peripheral Vascular Disease	Binary	DAD/Surginet	Peripheral vascular disease • CIHI-DAD on admission (DXTYPE = 1). Identify any of the following ICD codes: • ICD-10: I70,I71,I731,I738,I739,I771,I790,I792,K551,K558,K559,Z958,Z959 • Check Surginet for pre-admit clinical visit for history of any peripheral vascular disease
Cerebrovascular Disease	Binary	DAD/Surginet	Cerebrovascular disease • CIHI-DAD on admission. Identify any of the following ICD codes: • ICD-10: G45, G46, H340, I60-I69 • Check Surginet for pre-admit clinical visit for history of any cerebrovascular disease
COPD	Binary	DAD/Surginet	Chronic obstructive pulmonary disease • CIHI-DAD on admission. Identify any of the following ICD codes: • ICD-10: I278,I279,J40,J41,J42,J43, J44,J45, J46, J47,J60, J61, J62, J63, J64, J65, J66, J67, J684,J701, J703 • Check Surginet for pre-admit clinical visit for history of any COPD
Cancer	Binary	DAD/Surginet	History of cancer • CIHI-DAD on admission. Identify any of the following ICD codes: Primary Cancer: ICD-10: C0, C1, C20-C26, C30-C34, C37-C41, C43, C45-C58, C6, C70-C76, C81-C85, C88, C90-C97 Metastatic Cancer: ICD-10: C77-C80 • Check Surginet for pre-admit clinical visit for history of any cancer
Dementia	Binary	DAD/Surginet	Cognitive impairment/ dementia • CIHI-DAD on admission. Identify any of the following ICD codes:

			ICD-10: F00,F01,F02,F03,F051, G30,G311,G041,G114,G801,G802,G81,G82,G830,G831,G832, G833,G834,G839 • Check Surginet for pre-admit clinical visit for history of any dementia
Dialysis	Binary	Surginet	Check Surginet for history of dialysis • CCP: 51.95, 66.98 • CCI: 1PZ21HQBR, 1PZ21HPD4
MI	Binary	DAD/Surginet	Past myocardial infarction • CIHI-DAD on admission. Identify any of the following ICD codes: • ICD-10 codes: I21, I22, I252 • Check Surginet for pre-admit clinical visit for history of any MI
Ischemic Heart Disease	Binary	DAD/Surginet	Ischemic heart disease • CIHI-DAD on admission. Identify any of the following ICD codes: • ICD-10 codes: I20-I24 • Check Surginet for pre-admit clinical visit for history of any IHD
Heart Failure	Binary	DAD/Surginet	History of heart failure • CIHI-DAD on admission. Identify any of the following ICD codes: • ICD-10 codes: I099, I255, I420, I425, I426, I427, I428, I429, I43, I50, P290 • Check Surginet for pre-admit clinical visit for history of any heart failure
Left Ventricular Ejection Factor	Number	CorHealth	Left ventricular ejection fraction • Check the variable value "CATH_LVEF" in CCN database • 1 for ≥50% • 2 for 35% - 49% • 3 for 20% - 34% • 4 for <20% Flag if the variable value is missing
CCS Class		CorHealth	
NYHA Classification		CorHealth	**NYHA Classification of heart failure**
Previous Cardiac Surgery	Binary	CorHealth	
Use of Assist Devices		CorHealth	-LVAD
Creatinine Levels	Number	Cerner	

medications	text	Cerner	1. List of medications pre-admission, listed by admission med reconciliation 2. List of medications ordered through duration of hospital stay

Perioperative Factors			
Variable	Type/format	Source database	Description
Admit category	Text	Surginet/DAD	Elective Emergent
Pre-operative hemoglobin	g/L	Cerner	Lowest recorded hemoglobin in the 3 months before surgery
Pre-operative Serum creatinine		Cerner	Highest recorded creatinine in the 3 months before surgery
Pre-operative Serum albumin	g/dL	Cerner	
Procedure duration		Surginet/DAD	
Pump time	Number	Perfusion Data	
Blood transfusion given	Y/N	Surginet/DAD	Indicates whether the patient received a blood transfusion using blood
Blood components/products	Y/N	Surginet/DAD	Red Blood Cells Platelets Plasma Albumin Other Blood Product
Use of Heart Lung Machine	Binary	Surginet/DAD	
Robotic Surgery	Binary	Surginet/DAD	
Intraortic Balloon Pump	Binary	Surginet/DAD	
ECMO	Binary	Surginet/DAD	

Postoperative Factors			
Variable	Type/format	Source database	Description
ICU admission	Y/N	Surginet/DAD	Service transfer service Service transfer subservice Special Care Unit Number
CCU admission	Y/N	Surginet/DAD	Service transfer service Service transfer subservice Special Care Unit Number
Return to Operating Room	Binary	Surginet/DAD	

Admission to any other special unit	Y/N	Surginet/DAD	Service transfer service Service transfer subservice Special Care Unit Number
SCU Admit Date	YYYYMMDD	Surginet/DAD	Date the patient was admitted to a special care unit number
SCU Discharge Date	YYYYMMDD	Surginet/DAD	Date the patient was discharged from or expired on a special care unit
Discharge Date	YYYYMMDD	Surginet/DAD	The date the patient was formally discharged.
Length of stay in ICU/CCU	Days	Calculated	Days from surgery completion to discharge from the unit
Length of stay in hospital	Days	Calculated	Days from surgery completion to discharge from the hospital
Complications (DXTYPE = 2 or by CCI code in DAD)	Categorical		E.G. Acute Kidney Injury or Dialysis (All complications) -all Type 2 diagnosis codes on the visit
Discharge Disposition	Categorical		E.G. Discharge, Dead or Alive

Case-Costing			
Variable	Type/format	Source database	Description
VariableDirectLabourPlus Cost Code: VDL	Case-costing		Labour Costs that vary directly & proportionately with direct patient care activities
VariableDirectMaterial Cost Code: VDMGS	Case-costing		General supply costs that vary directly & proportionately with direct patient care volume
VariableDirectMaterial Cost Code: VDMPSS	Case-costing		clinical supply costs that can be traced to specific patients and vary directly & proportionately with direct patient care volume
VariableDirectLabourPlus Cost Code: VDO	Case-costing		Expenses paid to contractors which vary directly & proportionately with direct patient care volume
FixedDirect Cost Code: FDL	Case-costing		Labour costs that remain constant to support direct patient care
FixedDirect Cost Code: FDO	Case-costing		Sundry

FixedDirect Cost Code: FDBEG	Case-costing		Maintenance costs that remain constant supporting direct patient care activities
Indirect Cost Cost Code: FI	Case-costing		

Variables to be created			
Variable	Type/format	Source database	Description
Socioeconomic status	quintile		Created from ON-Marg Index
Obesity	Categorical	To be created	Created from BMI

Appendix B: Forward Sortation Areas

fsa n (%)	fsa n (%)	fsa n (%)	fsa n (%)	fsa n (%)
B4N 1 (0.0)	N0E 9 (0.3)	N4X 14 (0.4)	N7D 1 (0.0)	N9K 4 (0.1)
J7V 1 (0.0)	N0G 19 (0.6)	N4Z 3 (0.1)	N7F 1 (0.0)	N9N 2 (0.1)
K0H 1 (0.0)	N0H 19 (0.6)	N5A 25 (0.7)	N7G 47 (1.4)	N9V 69 (2.1)
K0J 1 (0.0)	N0J 35 (1.0)	N5C 31 (0.9)	N7L 92 (2.8)	N9Y 43 (1.3)
K0L 1 (0.0)	N0K 21 (0.6)	N5H 27 (0.8)	N7M 78 (2.3)	N9Z 1 (0.0)
K1K 1 (0.0)	N0L 122 (3.7)	N5L 9 (0.3)	N7N 2 (0.1)	NUL 1 (0.0)
K2M 1 (0.0)	N0M 161 (4.8)	N5N 1 (0.0)	N7P 1 (0.0)	P0M 1 (0.0)
K7C 1 (0.0)	N0N 119 (3.6)	N5P 58 (1.7)	N7S 80 (2.4)	P0N 1 (0.0)
K9J 1 (0.0)	N0P 181 (5.4)	N5R 66 (2.0)	N7T 75 (2.2)	P0S 1 (0.0)
L0N 1 (0.0)	N0R 122 (3.7)	N5V 60 (1.8)	N7V 38 (1.1)	P2A 1 (0.0)
L0R 2 (0.1)	N1G 1 (0.0)	N5W 56 (1.7)	N7W 16 (0.5)	P3B 1 (0.0)
L1C 1 (0.0)	N1H 1 (0.0)	N5X 61 (1.8)	N8A 46 (1.4)	P3P 1 (0.0)
L1N 2 (0.1)	N2A 1 (0.0)	N5Y 45 (1.3)	N8H 71 (2.1)	P5N 1 (0.0)
L1Z 1 (0.0)	N2E 1 (0.0)	N5Z 49 (1.5)	N8L 1 (0.0)	P6A 2 (0.1)
L2E 1 (0.0)	N2H 1 (0.0)	N6A 17 (0.5)	N8M 41 (1.2)	P6B 1 (0.0)
L2H 1 (0.0)	N2L 1 (0.0)	N6B 26 (0.8)	N8N 64 (1.9)	P7B 1 (0.0)
L3B 1 (0.0)	N2V 1 (0.0)	N6C 64 (1.9)	N8P 17 (0.5)	P7C 1 (0.0)
L3R 1 (0.0)	N2Z 28 (0.8)	N6E 63 (1.9)	N8R 34 (1.0)	P7L 1 (0.0)
L3V 1 (0.0)	N3A 1 (0.0)	N6G 58 (1.7)	N8S 72 (2.2)	T3H 1 (0.0)
L4M 2 (0.1)	N3R 3 (0.1)	N6H 45 (1.3)	N8T 41 (1.2)	T4C 1 (0.0)
L4N 1 (0.0)	N3S 1 (0.0)	N6J 66 (2.0)	N8W 71 (2.1)	V2R 1 (0.0)
L6J 1 (0.0)	N3Y 1 (0.0)	N6K 79 (2.4)	N8X 51 (1.5)	
L6X 2 (0.1)	N4B 2 (0.1)	N6L 6 (0.2)	N8Y 41 (1.2)	
L9C 1 (0.0)	N4G 24 (0.7)	N6M 10 (0.3)	N9A 62 (1.9)	

L9P 1 (0.0)	N4K 6 (0.2)	N6N 5 (0.1)	N9B 37 (1.1)	
M1B 1 (0.0)	N4N 2 (0.1)	N6P 16 (0.5)	N9C 30 (0.9)	
M1C 1 (0.0)	N4S 28 (0.8)	N6V 1 (0.0)	N9E 33 (1.0)	
N0A 4 (0.1)	N4T 12 (0.4)	N7A 22 (0.7)	N9G 42 (1.3)	
N0B 3 (0.1)	N4V 3 (0.1)	N7B 1 (0.0)	N9H 24 (0.7)	
N0C 1 (0.0)	N4W 2 (0.1)	N7C 1 (0.0)	N9J 38 (1.1)	

Appendix C: List of Complications

0 = minor complication, 1 = moderate complication, 2 = major complication

ICD-10 code	importance
J9810	0
J9588	0
R609	0
I630	2
F058	1
I634	2
I4890	1
E877	0
D649	0
I442	2
I4800	1
T812	0
N141	0
J938	1
G459	2
D500	0
N2888	0
J9580	1
F059	1
K913	0
R310	1
R33	1
T814	1
D684	0
A410	2
N998	0
I460	2
T828	0
F113	0
I472	1
E875	0
I958	1
T8428	0
I959	1
T8183	0

I498	0
R570	2
D695	0
K264	0
E872	1
T810	1
J90	1
R000	0
I214	2
L0311	1
J069	0
I4891	1
D683	0
R55	2
I639	2
R498	0
A498	0
I500	1
T8188	1
G4090	2
I4900	3
A099	0
G4060	2
D696	0
I493	0
T817	0
N390	1
J81	0
R073	0
K2214	0
I978	0
S025	0
R111	0
R090	2
D689	0
J951	1
I240	0
J40	0
I308	0
N990	0
H538	0
I440	0
I210	2
R600	0
T813	1
A048	1

I631	2
I441	1
I4801	1
T811	1
N179	1
I469	2
T825	0
E039	0
D688	0
G8199	2
J189	1
J14	1
D62	1
R520	0
A047	0
J9609	0
I455	0
T885	1
I319	0
I518	0
G4010	0
T8279	0
J9699	0
A411	1
I635	2
A4151	2
J110	0
R53	0
T884	0
F419	0
H470	0
D735	0
G4031	0
K922	0
A4188	2
R001	0
R410	0
E871	0
A419	2
I724	0
S22200	0
E868	0
K720	0
I313	0
R112	0
I495	0

R104	0
J931	0
R060	0
H431	0
I471	0
I99	0
R739	0
E870	0
N289	0
R401	1
R470	2
I638	2
R601	0
N359	0
K3188	0
F104	0
R113	0
M548	0
A499	0
J9818	0
K602	0
I632	2
R098	0
J111	0
J3801	0
B027	0
M6282	0
K920	1
Z738	0
E1111	0
B029	0
I2382	1
R4188	0
K560	0
G570	0
D700	0
M968	0
R442	0
F03	0
I229	1
F050	1
G629	0
A4180	1
G9380	1
G451	0
M213	0

T822	1
S37391	0
R5688	0
I64	2
G8190	2
I483	1
I200	0
E876	0
G934	1
M1090	0
G563	0
I970	1
I971	1
I484	1
R688	0
T796	0
I443	0
E834	0
E139	0
H341	2
R652	0
J959	0
H490	0
J848	0
I309	0
D65	1
I447	0
R72	0
K566	0
K746	0
A480	2
G253	2
I501	1
G419	2
L0310	1
R238	0
K254	0
R2688	0
R400	0
R278	0
R1010	0
G8320	0
R443	0
T827	0
I499	0
G931	2

R068	0
J181	1
R42	0
J986	0
R318	0
R441	0
I249	1
L539	0
H540	0
T8181	0
G82391	2
J939	1
J9690	0
K559	0
T821	0
G8191	2
J985	0
J151	1
M319	2
K210	0
L898	1
G935	2
I744	0
J942	1
N471	0
R798	0
F220	0
N170	1
K573	0
H534	0
R451	0
J80	2
I653	0
I509	0
R4180	0
I652	0
T856	0
I951	0
J690	1
E274	0
G418	2
S0625	2
S032	0
K590	0
H532	0
J155	1

R9438	0
J158	1
I802	1
I952	0
U838	0
I517	0
I269	2
M316	0
R478	0
K625	2
H549	0
G470	0
K0887	0
I221	2
J156	1
I748	1
J9691	1
T857	0
K550	0
K565	0
K449	0
J22	0
I728	0
E890	0
G8109	0
E873	0
G4030	0
R14	0
K921	0
K729	2
U821	0
I233	2
R042	0
T403	0
R572	2
F412	0
R456	0
R578	1
M6280	0
T8468	0
J101	0
R740	0
I219	1
U832	0
J150	1
L024	0

T858	0
G729	0
R130	0
R789	0
N320	0
U830	0
I710	2
M6286	0
J982	0
R458	0
G902	0
J128	1
J152	1
R471	0
K6388	0
R748	0
T82700	0
Z991	2
T843	0
K9142	0
R208	0
R36	0
T82701	0
T179	0
R680	0

Appendix D: List of Abbreviations

ABF = activity-based funding

ACE = angiotensin-converting enzyme

ACS = Acute coronary syndrome

AIC = Akaike Information Criteria

BEG = building, equipment, and grounds

CABG = Coronary Artery Bypass Graft

CAD = Coronary Artery Disease

CAN-Marg = Canadian Marginalization Index

CCS = Canadian Cardiovascular Society

CIHI = Canadian Institute for Health Information

CL = comorbidity level

CMG+ = Case Mix Group

CORONARY = Coronary Artery Bypass Graft Off or On Pump Revascularization Study

DA = Dissemination area

DAD = discharge abstract database

ECMO =extracorporeal membrane oxygenation

ELOS = expected length of stay

FI = flagged intervention

FREEDOM = Future Revascularization Evaluation in Patients With Diabetes Mellitus: Optimal Management of Multivessel Disease

FSA = Forward sortation area

GDP = Gross Domestic Product

GLM = Generalized Linear Model

GS = Goods and Services

HBAM = Health based allocation model

HIG = HBAM Inpatient Group

HSFR = health system funding reform

ICU = intensive care unit

IE = intervention event

LAMA = Left against medical advice

LHSC = London Health Sciences Centre

MI = myocardial infarction

MOHLTC = Ministry of Health and Long-term Care

MRSE = Mean relative squared error

MSPE = Mean squared prediction error

NYHA = New York heart association

OLS = ordinary least squares

ON-Marg = Ontario Marginalization Index

OOH = out-of-hospital

PBF = patient-based funding

PCI = Percutaneous coronary intervention

PSS = Patient specific supplies

QBP = Quality-Based Procedure

SCU = special care unit

SES = Socioeconomic status

SYNTAX = Synergy Between Percutaneous Coronary Intervention With TAXUS and Cardiac Surgery

TAVI = trans-catheter aortic valve implantation

WISE = Women's Ischemia Syndrome Evaluation

Appendix E: Association between Socio-economic Status and Co-morbid Conditions

Table 11a: Relationship between SES Factors and Comorbid Conditions (Instability)

	Test Performed	p-value
Diabetes	Chi-squared Test	0.7281
Hypertension	Chi-squared Test	0.8198
Hyperlipidemia	Chi-squared Test	0.2329
Peripheral Vascular Disease	Chi-squared Test	0.1298
Cerebrovascular Disease	Chi-squared Test	0.8663
Chronic Obstructive Pulmonary Disease	Chi-squared Test	0.0792
Cancer	Chi-squared Test	0.8281
Dementia	Chi-squared Test	0.6329
Dialysis	Chi-squared Test	0.6968
Ischemic Heart Disease	Chi-squared Test	0.0047
Heart Failure	Chi-squared Test	0.0373
Obesity	Chi-squared Test	0.3620

Table 11b: Relationship between SES Factors and Comorbid Conditions (Material Deprivation)

	Test Performed	p-value
Diabetes	Chi-squared Test	0.0184
Hypertension	Chi-squared Test	0.2565
Hyperlipidemia	Chi-squared Test	0.1281
Peripheral Vascular Disease	Chi-squared Test	0.0301
Cerebrovascular Disease	Chi-squared Test	0.9223
Chronic Obstructive Pulmonary Disease	Chi-squared Test	0.0387
Cancer	Chi-squared Test	0.2136

Dementia	Chi-squared Test	0.0900
Dialysis	Chi-squared Test	0.5975
Ischemic Heart Disease	Chi-squared Test	0.2811
Heart Failure	Chi-squared Test	0.2391
Obesity	Chi-squared Test	0.0003

Table 11c: Relationship between SES Factors and Comorbid Conditions (Dependency)

	Test Performed	p-value
Diabetes	Chi-squared Test	0.9570
Hypertension	Chi-squared Test	0.1078
Hyperlipidemia	Chi-squared Test	0.8028
Peripheral Vascular Disease	Chi-squared Test	0.4515
Cerebrovascular Disease	Chi-squared Test	0.2483
Chronic Obstructive Pulmonary Disease	Chi-squared Test	0.1815
Cancer	Chi-squared Test	0.6487
Dementia	Chi-squared Test	0.8518
Dialysis	Chi-squared Test	0.8252
Ischemic Heart Disease	Chi-squared Test	0.4666
Heart Failure	Chi-squared Test	0.2222
Obesity	Chi-squared Test	0.9459

Table 11d: Relationship between SES Factors and Comorbid Conditions (Ethnic Concentration)

	Test Performed	p-value
Diabetes	Chi-squared Test	0.5518
Hypertension	Chi-squared Test	0.2983
Hyperlipidemia	Chi-squared Test	0.8737
Peripheral Vascular Disease	Chi-squared Test	0.2108
Cerebrovascular Disease	Chi-squared Test	0.4807
Chronic Obstructive Pulmonary Disease	Chi-squared Test	0.4453
Cancer	Chi-squared Test	0.4632
Dementia	Chi-squared Test	0.4346
Dialysis	Chi-squared Test	0.1310
Ischemic Heart Disease	Chi-squared Test	0.1451
Heart Failure	Chi-squared Test	0.6800
Obesity	Chi-squared Test	0.0034

Curriculum Vitae

Name:	Hun (Steven) Lee
Post-secondary Education and Degrees Conferred:	University of Illinois at Urbana-Champaign Urbana, Illinois, USA 2016-2017 Master of Mathematics – Actuarial Science (Withdrawn)
	Columbia University in the City of New York New York City, New York, USA 2015-2016 Master of Arts in Quantitative Methods in Social Sciences
	Columbia University in the City of New York New York City, New York, USA 2014-2015 Graduate Certificate in Economics
	McGill University Montreal, Quebec, CA 2009-2014 Bachelor of Science in Chemistry
Honours and Awards:	Lawson IRF Studentship 2019
Related Work Experience:	Statistical Analyst Department of Medicine, Western University 2020-present
	Teaching Assistant Western University 2019-2020
	Research Analyst Ivey International Centre for Health Innovation 2018-2019