THE BURDEN OF CANCER: INDIVIDUAL AND SOCIETAL OUTCOMES

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Lay abstract

In 2017, there were approximately 206,200 new cancer diagnoses in Canada, and 1 in 2 Canadians are currently expected to develop cancer in their lifetime. The chances are that most Canadians may know someone—likely more than one person—who has been afflicted with cancer. As more Canadians are diagnosed with cancer and survive, researchers are increasingly trying to understand and describe the short- and longer-term impact of cancer on health and social role engagement (particularly paid work) of afflicted individual, with the intent of identifying ways to minimize adverse outcomes.

The following chapters investigate the impact of a cancer diagnosis on annual labour market earnings, health, and the aggregation of these and other impacts on the societal economic burden. Chapter 1 sets the context for the entire thesis and draw out the overall objectives and motivations of the work. In Chapter 2 I conduct a comprehensive costing evaluation to estimate the economic burden of occupational cancer, taking a societal perspective, and provide a detailed breakdown of items that contribute to the economic burdens of cancer. In Chapter 3 I estimate the change in labour market earnings due to cancer diagnosis over a period of 5 years to uncover the heterogeneous effects of cancer type on labour market earnings. Finally, in Chapter 4 I estimate the impact of cancer on health using three different health indicators. In Chapter 5 I summarize the findings and contributions of each study.

Abstract

It is paramount that an accurate assessment of the impact of a cancer diagnosis is available with which to plan future resource allocation and to highlight the area to direct future policy initiatives.

In the second chapter I take a modelling approach to estimate the economic burden of bladder cancer due occupational exposure. Using a multi-stage Markov model, I estimate direct, indirect, and intangible lifetime costs of bladder cancer starting in the year 2011. The results of this analysis indicate that there is a substantial economic burden associated with occupational bladder cancer. Of the three components that make up the total economic costs, intangible costs represent the largest proportion, followed by indirect and direct costs.

In the third chapter, I use a data set created via a linkage of several administrative data resources to estimate the relationship between cancer diagnosis and annual labour market earnings. Using the Mahalanobis' distance and propensity score matching combined with a difference-in-difference regression, I isolate the impact of cancer diagnosis on labour market earnings of cancer survivors by comparison to their peers without cancer. There are two conclusions that can be derived from the results. First, I found that cancer survivors recover a fraction of their labour market earnings over time as they are further removed from the time of the cancer diagnosis. Secondly, I found the heterogeneous effects of cancer where most cancer survivors showed a persistent loss of labour market earnings except breast, cervix, and skin cancer survivors in the less-active age group.

In the fourth chapter I examine the impact of cancer on health using three commonly used health indicators: life expectancy, Health Utility Index, and health-adjusted life expectancy.

Specifically, I decomposed the differences between individuals with and without cancer in above-mentioned indicators by age and cancer type—considering all cancer types, then specifically breast, colorectal and prostate cancers. The results of the study indicate the heterogeneous effects of cancer on health outcomes and provide a repository of health outcome information that other researchers and policymakers can use.

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I would like to express my gratitude to the following people who have supported me throughout the Ph.D. degree, a life's journey summarized in a 5-year program.

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Secondly, I would like to thank my committee members, Prof. Emile Tompa and Prof. Philip DeCicca. I thank Prof. Emile Tompa for teaching me the value of good storytelling and precision in academic research. Most importantly, I thank you for continuing to push my thinking forward and sharing your expertise and knowledge with me. (I will miss our conversations about traveling and craft beers.) To Prof. Philip DeCicca, thank you for your compassion, kindness, and insight. (Also, all the lunches you took me out on during C711 course. The meals you've provided literally fueled me in finishing this journey.)

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Disclaimer

The research and analyses for Chapter 3 and 4 are conducted independently from the Statistics Canada. Therefore, the views expressed in the chapters three and four are solely those of authors and may differ from the Statistics Canada's views. The analyses of the second and the third chapters were conducted at Statistics Canada's Federal Research Centre (FRDC) in Ottawa, Ontario. I would like to thank the staff, especially Sukitha, Abeysekera for the generous assistance.

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List of all Abbreviations and Symbols

CanCHEC – Canadian long-form census health and environment cohort

CCDB – Canadian cancer database

CCHS – Canadian community health survey

CCR – Canadian cancer registry

CHEPA – Centre for health economics and policy analysis

CMDB – Canadian mortality database

DiD – Difference in difference

FRDC - Federal research data centre

HALE – Health adjusted life expectancy

HUI – Health utility index

HTA – Health technology assessment

ICD-3-O/H– International classification of diseases for oncology

ICD 10 – International classification of disease version 10

LE – Life expectancy

LFS – Labour force survey

OCRC – Occupational cancer research centre

OOPC – Out of pocket costs

QALY – Quality adjusted life years

SEER – The surveillance, epidemiology, and end results registry

T1FF – T1 family file

WHO – World health organization

WTP – Willingness to pay

Declaration of Academic Achievement

This thesis contains an introduction (Chapter 1), three original research studies (Chapter 2, 3 and 4), and concluding chapter (Chapter 5). I was responsible for the empirical analysis, participated in all stages of the research, and wrote the manuscripts. My supervisor, Dr. Christopher Longo, contributed to the design of Chapter 3 and 4, interpretation of results for all research chapters, and provided revisions for every chapter. Committee member, Dr. Emile Tompa, contributed to the design of Chapters 2,3 and 4, interpretation of results for all research chapters, and provided methodological guidance and revisions for every chapter. Committee member, Dr. Philip DeCicca contributed to the interpretation of results for Chapter 3 and provided revisions.

Chapter 1. Introduction

In this chapter I provide an overview of the rationale, objectives, and contributions of the three original studies (Chapters 2, 3, and 4). I first describe the questions that motivated my research, followed by the research agenda that I created to address these questions.

The rationale for undertaking research of the impact of cancer on individuals and society

Based on 2010 estimates (Canadian Cancer Society, 2018), approximately 1 in 2 Canadians is expected to develop cancer during their lifetime. In other words, experiencing cancer is ubiquitous; we all know someone who has been diagnosed with cancer at some point in their lifetime.

The motivation for this thesis stems from personal experience, from witnessing many family members and friends being diagnosed with cancer, suffering through treatment, and experiencing the deterioration of their personal lives and family structures. Many people think that the battle with cancer plays out in clinical settings, but in reality, much of the battle spills into everyday life, particularly at the individual and family levels. When a family member is diagnosed with cancer, it is like everyone has the disease; it changes family dynamics. The afflicted individual may reduce their labour supply or withdraw from the labour force all together. In response, family members, and particularly the spouse, may also reduce their labour supply in order to care for their sick partner.

While many of the experiences of individuals afflicted with cancer were known to me, I was bothered by the lingering questions about how cancer survivors fare over time after the initial diagnosis. As a health economist, I wondered, would the loss of annual labour market earnings be different according to cancer types? How persistent is the loss of the labour market

earnings? How do health outcome differ between individuals with and without cancer? What is the economic burden of cancer, and, conversely, how much can our society save by preventing cancer? A deeper examination of literature that investigates the impact of cancer revealed only partial answers to my questions: Studies often aggregate different types of cancer, and the follow-up periods are often not lengthy enough to reveal long-term impacts of cancer (Bernard, Farr, and Fang, 2011; Cohen, Gindi, and Kirzinger, 2011; Fenn et al., 2014). This lack of specificity motivated my decision to undertake studies to address the gaps. Hence, I set out to estimate the burden of cancer on individuals and society, in terms of health and earnings losses.

Approaches for the three studies

Each substantive chapter of the thesis is linked conceptually, and each builds on the insights gained from the preceding chapter(s). The methods I employ in each chapter are chosen to best address the objectives of the study in the chapter. The overarching objective of this dissertation is to quantify and examine the impact of cancer across different outcomes, particularly societal economic burdens, labour market earnings, and health. It is necessary to measure and quantify the impact of cancer before a discussion can take place on how to improve the welfare of individuals with cancer. The objectives of the thesis are to:

1. Estimate the economic burden of cancer to society, stratified by three stakeholders: individual, employer, and system (Chapter 2).
2. Investigate the relationship between labour market earnings and cancer survivorship over time. Particularly, to estimate the loss of annual labour market earnings by cancer types and age groups, using linked-administrative datasets (Chapter 3).
3. Estimate the health profile of individuals with cancer using three commonly used health indicators (Chapter 4).

As noted, many studies have highlighted the stark differences between individuals with and without cancer in terms of labour force participation (Bradley et al., 2005; Bednarek and Bradley, 2005), loss of labor market earnings (Jeon, 2017; Lauzier et al., 2013), and health outcomes (Bowker et al., 2006; Mittman et al., 1999). Despite prior investigations on the impact of cancer, there is a lack of clarity about the impacts of different cancer types and the long-term impacts of cancer more broadly.

The general approach to the order of these studies follow a *funnel principle* (Belt, Mottone and Harkonon 2010) where I narrow down the focus of research questions, starting from investigating the impact of cancer diagnosis at a societal level (Chapter 2) and ending with using micro-level datasets to look at the impact of cancer diagnosis at an individual level (Chapter 3 and 4). In the first study (Chapter 2), I provide an overview of the economic burdens of bladder cancer. The study provided an insight that there are underlying factors that influence how individuals with cancer respond to cancer diagnosis. Using linked-administrative data I address the unanswered empirical question identified in Chapter 2, particularly the long-term effects of cancer diagnoses on labour market earnings by different cancer types in Chapter 3. Using a combination of population survey and administrative datasets, I focus on estimating the health profiles of the individuals with cancer by different cancer types in Chapter 4. Together, these three studies form a cohesive body of work that draws a picture of the comprehensive impact of a cancer diagnosis at both an individual and societal level.

Thesis contributions

Each study examines the impact of cancer and thereby contribute substantive new information and providing a level of detail to the area of health economics in cancer.

The first study (Chapter 2) exploits the unique opportunity provided by the Occupational Cancer Research Centre, where newly identified bladder cancer cases due to occupational exposure were estimated using an approach similar to the one used by the United Kingdom Burden of Occupational Cancer study (Brown et al., 2012). I attempt to estimate the total lifetime economic costs for individuals who are diagnosed with bladder cancer following the approach developed by Tompa et al. (2017) for occupational asbestos exposure. Specifically, I took an incidence approach to estimate economic costs associated with cancer from the moment of the diagnosis. Additionally, I use a Markov model (Briggs and Sculpher, 1998) to reflect the complexity of the disease and an individual's change in labour market activities over their lifetime.

One of the contributions that I make to the literature is the decomposition of total economic costs into direct, indirect, and intangible costs for bladder cancer, as well as applying probabilistic sensitivity analysis to provide a detailed description of items included in each cost category, taken for the methodology of a larger initiative on the economic burden of occupational cancer (Tompa et al., 2017). Lastly, per case burden estimates can be used as a policy tool to draw attention to the issue, raise awareness of occupational cancer, and direct more resources to prevent occupational cancer.

I consider the heterogeneous effects of cancer types in the second study (Chapter 3) as there are relatively few studies that have examined the loss of labour market earnings by cancer

types over the long-term (Bennett et al., 2009; Jeon, 2017; Lauzier et al., 2008; Sharp and Timmons, 2010**)**. The second study (Chapter 3) is a detailed investigation of a temporal relationship between cancer diagnoses and cancer survivors' loss of labour market earnings over a period of five years after the initial diagnoses. The research was made possible through the availability of linked administrative datasets that are housed at Statistics Canada, Ottawa, Canada. I identify newly diagnosed cancer cases in a linked database of the Canadian Cancer Registry, the Canadian Cancer Database, the 1991 Census of Population, Family Income Files (T1FF), and Vital Statistics. In terms of methodologically, I use the Mahalanobis' distance and propensity score matching (Rosenbaum and Rubin, 1985) and a difference-in-difference regression method to isolate the impact of cancer and estimate the loss of labour market earnings. The findings from Chapter 3 suggest that loss of labour market earnings is associated with severity of cancer type, and that cancer survivors start to recover their labour market earnings two years after the initial diagnosis.

In the third study (Chapter 4) I estimate the health profile of individuals with cancer using three health indicators: life expectancy, Health Utility Index Mark III, and health adjusted life expectancy. Using the Canadian Cancer Registry and Canadian Vital Statistics, I estimate the number of deaths, mortality rate, and probability of death due to all types of cancer, with a focus on breast, prostate, and colorectal cancer. Separately, using data from the 2010 and 2014 Canadian Community Health Survey, I estimate the distribution of Health Utility Index (HUI3) between individuals with and without cancer stratified by sociodemographic characteristics and cancer type. Combing the information derived from the aforementioned datasets, I estimate health adjusted life expectancy between the individuals with and without cancer in Canada, and across three different cancer types. Chapter 4 is centered on combining existing methodologies to

measure health profiles between individuals with and without cancer. Detailed instructions on sample selection, appropriateness of data, and importance of each health indicator are all presented in the hopes that it will provide a snapshot of the health profile of individuals with cancer in Canada.

The three studies provide insight into how and the degree to which cancer can impact various outcomes contribute to the well-being of individuals with cancer. Cancer has society-wide implications (Chapter 2), long-term effects on survivor's labour market earnings (Chapter 3), and health outcomes that differ by type of cancer (Chapter 4). Finally, the idea that the burden of cancer is both economically and statistically significant, and confirmation that cancer types can have different impacts at the individual level on health, earnings and well-being, is a key contribution of this thesis.

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Ch.2. The Economic Burden of Bladder Cancer due to Occupational Exposure

Preface

I was responsible for the empirical analysis and participated in all stages of the research. Dr. Emile Tompa aided in framing the research question and approach to study design. Analyses and interpretation of the results were developed through series of discussions with Drs. Emile Tompa and Christopher Longo. I drafted the manuscript based on the feedback received from Drs. Emile Tompa and Christopher Longo.

The manuscript was accepted for publication in November 2017 and published on March 2018. These analyses were undertaken at the Institute for Work and Health and McMaster University. This chapter has been published in the *Journal of Occupational Environmental Medicine*. Written permission has been provided to McMaster University to reprint this article as part of this thesis.

Ch.2. The Economic Burden of Bladder Cancer due to Occupational Exposure

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Abstract

Objective: To estimate the economic burden of bladder cancer due to occupational exposures.

Methods: Using a societal perspective, we estimate the lifetime costs of newly diagnosed cases of bladder cancer in Canada that is associated with occupational exposure for the calendar year 2011. The three major categories we consider are direct, indirect, and quality of life costs.

Results: There were 199 newly identified cases of bladder cancer. The estimated total cost of bladder cancer for new cases in 2011 was $131 million and an average per-case cost of $658,055 CAD (2011 dollars). Of the total costs, direct costs accounted for 6%, indirect costs 29%, and health-related quality of life costs 65%.

C**onclusions**: The per-case economic burden of bladder cancer due to occupational exposure is substantial which suggests the importance and value of exposure reduction.

Introduction

Cancer is one of the leading causes of premature death and the fourth leading cause of hospital admission in Canada.[1] According to the most recent report by Health Canada, in 1998 cancer care costs in Canada amounted to $14.2 billion.[2] This makes cancer the third costliest disease after cardiovascular and musculoskeletal diseases.[3] There are many studies that estimate the economic burden of cancer but many consider all types of cancer in one estimate, making it impossible to determine the impact of specific cancer types on the overall burden of illness. This single estimate approach is consistent with the common conception of cancer as a single disease but in reality, cancer is an umbrella term for many different diseases. Due to this, separate economic analyses for different cancer types are valuable for informing decision making, giving different treatment options, and prognoses.

Despite the increase in research on the economic burden of cancer few studies focus on bladder cancer[4] show that bladder cancer has the highest lifetime treatment cost per patient of all cancers in Canada due to preoperative and post-operative complications, high recurrence rates, intensive surveillance strategies, and expensive treatment costs.[5,6] Moreover, a similar study by Leigh[7] in the U.S identified bladder cancer as having the highest lifetime treatment cost per patient of all cancer types followed by colon and rectal, breast, prostate, and lung cancers. Bladder cancer is the fifth most commonly diagnosed malignancy in Canada with 8,000 incident cases and 2,200 expected deaths in 2014.[8] U.S. estimates revealed that 74,690 new cases and 15,580 deaths would be observed in 2014.[9]

Several published studies consider the economic burden of specific cancer types due to occupational exposure. For example, Leigh et al[10] identified the economic burden of several cancer types due to occupational exposures in the United States. Similar studies have been

conducted in Australia[11] and Britain.[12] In the Canadian context, only Krueger et al[13] and Orenstein[14] conducted studies on occupational skin cancer and a number of occupational cancers, respectively. Yet, there is no published, comprehensive study of the economic burden of bladder cancer due to occupational exposure for Canada or any other country. The scarcity of economic burden studies on occupational exposure is likely due to data limitations. Specifically, the long latency period from exposure to the onset of disease makes it difficult to identify the attributable fractions required to estimate the number of cancer incidents directly related to exposure at a specific location and time.

There is also a growing interest in better understanding the number of cancers attributed to occupational exposures and their economic burden for primary prevention efforts. Estimating the number of newly diagnosed cases and quantifying the economic burden of bladder cancer associated with occupational exposures provides important information for policy decision making in the occupational health and safety arena. Knowledge about the magnitude and number of bladder cancers can mobilize key interest groups. For example, if the burden is particularly high, a separate cost-effective analysis can be undertaken to estimate the value of prevention efforts. Per-case burden estimates are a key input into such analyses.

In general, there is insufficient knowledge on the health trajectories of occupational bladder cancer cases and their economic burden. Methods to estimate such burdens are also underdeveloped. The objective of this study then is to estimate the societal economic burden of bladder cancer, including health related quality of life years, by focusing on the lifetime costs of newly diagnosed cases in 2011 attributed to occupational exposures.

Methodology

Occupational Exposure

A team of researchers from the Occupational Cancer Research Centre (OCRC) estimated the number of newly identified bladder cancer cases in 2011 due to aromatic amines, occupational aluminum production, and painting and rubber production exposure in the Canadian context following an approach similar to the Burden of Occupational Cancer Study in the United Kingdom.[15] There is significant evidence showing that these exposures cause bladder cancer. The OCRC team attributed a proportion of the total number of newly diagnosed cancer cases in 2011 to workplace exposures based on a review of population-based case control studies. These studies assessed the magnitude of workplace exposures and related bladder cancer cases that ensued from the aforementioned exposures. Table 1 provides further details of those case estimates. Four types of exposures/activities – aromatic amines, aluminum production, painting, and rubber production – were found to be significantly associated with bladder cancer.

Table 1: List of Carcinogens linked to Bladder Cancer

Economic Framework

There are two major types of economic burden studies – prevalence and incidence-based cost studies. A prevalence study includes both long-standing and newly diagnosed cases in its estimates and generally considers costs incurred in a particular calendar year. This type of study is advantageous for identifying the magnitude of the total burden in a particular reference year. However, economic burden estimates using the prevalence-based costing approach tend to be disproportionally dominated by the small number of cases in the chronic/costly and late stages of illness. Additionally, since only within-year costs are generally considered, lifetime costs of cases are not identified. Another drawback of the prevalence case model is the danger of defining the economic burden in terms of what is currently being incurred rather than what will be

incurred going forward. This raises a number of challenges for setting priorities between different prevention measures as well as allocating scarce health care resources for treatment alternatives. In contrast, the incidence-based approach considers only newly diagnosed cases in a particular reference year and generally considers lifetime costs of cases. Such estimates are better suited as inputs into economic evaluations of prevention studies. Information on newly diagnosed cases is important for understanding what burdens could be avoided in future years if exposures are eliminated. Specifically, such case costing information can be used to evaluate the costs and benefits of interventions that eliminate exposures and reduce new cases of cancer.

Combined with the knowledge of disease progression, survival rates, and the impact of the illness on lifetime earnings, the incidence-based approach is more suitable for the objective of this study, which is to estimate the economic burden of newly identified bladder cancer cases due to occupational exposure. With this in mind we adopted the incidence-based model and considered only new cases of bladder cancers first diagnosed in the calendar year of 2011.

Drawing on the methods of a recently published study[16], we consider three major cost categories – direct, indirect, and quality of life or intangible costs. The first includes primary health care products and services. The second includes costs associated with economic output and loss of productivity from employment. The last category includes losses in the health utilities index (HUI) associated with social role functioning and the intrinsic value of life captured by Quality Adjusted Life Years (QALYs). The distinctions between costing categories are important for our methodological approach since the objective of the study is to separate the health impacts on labour market-related costs from the intrinsic value of social role function (labelled quality of life costs). A similar approach was adopted by Mackenbach et al[17] and Tompa et al[16], where the studies considered a change in health related-quality of life as one of the key outcomes. In recent

years, the World Health Organization[18] reiterated the importance of capturing social costs in burden studies, especially for individuals who are not captured in the labour force but suffer health shock. In general, we take a marginal cost approach where we consider the incremental cost of occupational bladder cancer compares to non-cancer cases (i.e., counterfactual). Costs by the key stakeholders are shown in Appendix 1. Supplementary Table 1 and 2 highlight the breakdown of each component of costs and health utilities.

Markov Model

We use a Markov model to estimate the direct costs, indirect costs, and quality of life measures associated with bladder cancer. The Markov models are particularly useful when a decision context involves a risk that persists over time with multiple complexities. The details of the Markov model are illustrated in Figure 1, which includes the probability of developing bladder cancer, the risk of progression to the next stage of cancer, the risk of recurrence, the risk of mortality with any case, whether sick or healthy, and the chance of making a full recovery. The model characterizes a case's prognosis in terms of five states – these include death and cancer free states and the remaining three states reflect the stages of cancer (the least severe cancer state is Type Ta and the most severe states are T2/T3/T4). The decision was made to simplify cancer stages into three groups in alignment with the clinical and treatment paradigm adopted at the Department of Urology, Cleveland Clinic, USA[19] as the five-year survival rate can be combined into localized (Ta), regional (T1) and distant stages (T2/T3/T4). The key structural assumption in this model is that cases can either remain in the same state or advance; a cancer case is less likely to recede to a less severe state. The second assumption is based on the exclusiveness of each state. That is, a case can only be in one state at a time. In conjunction with the objective of the

study, the aforementioned assumptions allow us to simplify the model while keeping the elements of authenticity within the prognosis of bladder cancer cases.

All the events of interest are modeled as transitions from one state to another. Each state is assigned a utility and the contribution of this utility to the overall prognosis depends on the length of time spent in a specific state. The time horizon of the analysis is divided into equal increments of time. During each cycle, the case may make a transition from one state to another. Based on The Alberta Oncology Guideline[20] we adopted a five-year time horizon and assumed that cases would return to a normal pattern of life and work after five years of successful treatments and follow-ups.

The model yields the average number of cycles spent in each stage along with the transition probabilities which represent the probability that a case will move to another stage and the probability distribution among all stages. Each stage is assigned a utility value which is calculated using the equation below.

$$\text{Expected Utility} = \sum_{s=1}^{n} P_s \times HUI_s \qquad (1)$$

Note:

- P_s = probability of survival of each stage of cancer
- HUI_s = Health Utilities Index of each stage of cancer

Figure 1: Markov model for bladder cancer

Data sources for model parameters

Annual direct medical costs and utility values associated with the treatment of bladder cancer were estimated at the average level across the different stages of cancer. The list of itemized costs and the utility value associated with each state is listed in supplementary table 1 and 2 respectively. The costs were accrued from the time of diagnosis until death. All costs were reported in 2011 Canadian dollars and discounted to 2011 at a 3% rate for values flowing in subsequent years.

Direct Cost

Direct cost refers to the cost of health care products and services whether publicly or privately financed. This includes costs associated with diagnosis, consultation, treatment, as well as post-treatment follow-up and end of life care. In this study, the following items are considered: 1) pre-surgery costs (cost of general practitioner consultation, urologist consultation, cost of diagnostic, and imaging services); 2) chemotherapy and radiotherapy; 3) cost of surgery (radical cystectomy); and 4) post-surgery costs (follow-up consultations, medical oncologist consultation, and post-operative complications management). All health care related costs were adjusted to 2011 Canadian dollars and shown in supplementary table 1.

Other direct cost components include care provided by the family and community, out of pocket costs (OOPC) for transportation to primary care service delivery sites, parking, prescription drugs, home health care, and accommodation. Based on Van Houtven et al[21] and Longo et al[22], we assumed that family members provide up to 16 hours per week of caregiving. This was converted to a monetary value based on a conservative current wage and future minimum wage projections, which we based on a 2% annual increase after the 2011 calendar year.

Indirect costs

Indirect costs refer to the loss of economic output associated with paid labour-market activity due to both morbidity and mortality. To estimate the loss of output due to poor health or premature death we use survival probabilities from the Surveillance, Epidemiology, and End Results Registry (SEER)[23] and 5-year survival probability data from Cancer Care Ontario. For long-term outcomes, we follow the Alberta Oncology Guideline[20] which assumes that cancer patients return to a normal pattern of personal and work life after five years of on-going treatment and follow-up care.

The two main approaches we used for estimating the loss of output and productivity were the friction and human capital methods. The former approach[24] reflects short term costs for employers due to the employee's unexpected withdrawal from the labour force, which subsequently disrupts the flow of business and economic production. The economic costs borne by the employers include costs involved with recruiting, training, and the loss of productivity until the new employee reaches the same level of production as the previous one. The aforementioned economic costs were estimated to be 50% of the replaced worker's wage for six months. At the individual and societal levels, the long-term burden of morbidity and pre-mature mortality due to bladder cancer is manifested through a reduction in labour force activity and its related output value, which we estimate using the human capital approach.[25] As a price weight, we use full wage values that include wages and fringe benefits. Cancer diagnosis can result in both short- and long-term loss of activity in home production, for which we also used the human capital approach. Subsequently, we sum the various productivity and output losses, as has been done in some recent societal-level burden studies[26], to estimate the costs to individuals, employers, and society at large.

Average Canadian labour-market earnings are used as price weights for market output loss estimates. To estimate the average labour-market earnings of occupational cancer patients, we use data from the Canadian Labour Force Survey (LFS) from 2011 and the Canadian Survey of Labour and Income Dynamics from 2010. For employer adjustment costs, we assumed a friction period of six months, or 50% of annual wages. These costs are assumed to be incurred in the year of diagnosis.[27] The following equation summarizes the present value of the lost output calculations.

$$PV_i = \sum_{n=y}^{90} P_i W_i (1 + F) E_i \left(\frac{1+g}{1+r}\right)^{n-y} \quad (2)$$

Note:

- P is the probability of survival
- W is average earnings
- F is fringe benefit proportion
- E is employment rate
- g indicates productivity growth
- r is the discount rate
- y is the age at the time of diagnosis

To account for the number of individuals with occupational cancer, this PV calculation was multiplied by the number of workers diagnosed with cancer in 2011. To account for growth in economic production and change in inflation, we used a moderate rate of 1% increase in productivity growth and a 3% discount rate, with a variation of 1.5 and 5% for sensitivity analysis.

Quality of Life Costs

The cost categories considered above (direct and indirect costs) are focused on measurable economic loss associated with the onset of cancer. However, if one were to follow the course of cancer treatment it would become abundantly clear that the diagnosis of cancer and the ensuing treatments negatively affect the health and well-being of cancer patients, over and above market impacts, which can be substantial. Consequently, if we do not consider the loss of well-being and quality of life due to cancer, our study would fail to capture the full burden of cancer. The Quality Adjusted Life Years (QALYs) attempts to address this. QALYs combine both the morbidity level of a particular health state (measured between 0 (death) and 1 (perfect health)) and the duration of time in that state. Additionally, patients are assigned a disutility value for each treatment for bladder cancer. Conceptually, the construct of health-related quality of life as measured with QALYs is distinct from productivity and related labour-market earnings. It measures the value of health in social role engagement, as well as the pain, suffering, and loss of enjoyment associated with poor health. In order to ensure there is no overlap between QALYs and measure of productivity loss, the study presents direct and indirect costs separately from QALYs, and additional sensitivity analysis was undertaken to address the potential double counting issue.

In an ideal scenario, utility value will be assessed and collected alongside a prospective clinical study. On the other hand, since most economic burden studies are undertaken using analytic modeling, a routinely available data source is used. In our case, utility values were obtained from the published medical literature[28] that corresponds with population setting, treatment paradigm, and the instrument to measure health-related quality of life (HUI-3) in a Canadian setting. The QALY values we use are drawn from the Markov/Disease model, described above, that considers a five-year period beginning at diagnosis. Marginal difference in

QALYs for cases are estimated by comparing case QALYs with that of the general population, stratified by age bracket and sex. QALY values for the general population are based on the Health Utility Index 3(HUI-3) from the 2010 Canadian Community Health Survey. As noted, health-related quality of life is assumed to be similar to the general population for cases surviving 5 years from diagnosis. The following equation summarizes our approach to measuring loss of QALYs due to bladder cancer.

$$N_{ij} \times f(n) \times \mathrm{MVQ} \times \sum_{n=0}^{\mu} \frac{(\mathrm{PS_G} \times \mathrm{HRQL_G} - \mathrm{PS_P} \times \mathrm{HRQL_P})_n}{(1 + \text{discount rate})^n} \quad (3)$$

Note:

- *N_{ij}= Number of cancer patients by age and sex*
- *PS_G = Probability of survival of general population*
- *PS_P = Probability of survival of case (personal experienced work injury or illness)*
- *$HRQL_G$= Health-related quality of life for general people*
- *$HRQL_P$= Health-related quality of life for case*
- *MVQ= Monetary value for a QALY*
- *μ= refers to an upper limit of years over which the computation is to be estimated—this should be some value larger than the maximum years of life remaining*
- $f(n)=\begin{cases} 0.5, & n=0 \\ 1.0, & n\neq 0 \end{cases}$ *(Use of 0.5 in equations is based on the assumption that, on average, cases are identified in mid-year and die in mid-year*

The health technology assessment (HTA) literature offers a range of methods and values for converting QALYs into monetary values. The value for QALYs we used is $50,000 CAD. This

value is commonly used in the Canadian health technology assessment field. However, based on a review of the relevant literature,[17,29-32] it was noted that a range of $50,000 to $100,000 was used to convert QALYs to monetary values in the Canadian setting. Thus, we used both the minimum and maximum value from the aforementioned reference to carry out a sensitivity analysis. A clear distinction needs to be made here: the key assumption is that monetary value per QALY reflects the government's willingness to pay (WTP) and not that of cancer patients since individuals receiving treatments can have a higher WTP.

Addressing uncertainty

A common practice to deal with imperfect information around the variables of interest is to carry out a simple one-way sensitivity analysis. However, simple sensitivity analysis has its limitations when the multiple variables, such as cancer patients' prognoses, labour outcome, a rate of return to work, and health utility index, are associated with some degree of uncertainty. Following the recent NICE guideline,[33] the recommended way to address the implications of multiple sources of uncertainty is to concurrently consider the distribution of all key parameters subject to uncertainty then fed into the Markov model to generate an outcome of interest. For example, we used a beta distribution to pool and describe the probabilities of transition probabilities, gamma distribution to describe and calculate the distribution parameters, and applied a relatively large standard error of 15% to each utility and disutility value.

In our investigation, we used the probabilistic sensitivity analysis to generate 5,000 sample distributions of the joint mean health care costs, state transition probability, and the QALYs to quantify the uncertainty of estimates related to costs of morbidity, mortality, and loss of health-related quality of life due to bladder cancer. To elaborate, an alpha and beta estimate is derived for the state transition probability based on the sample distribution from multiple clinical

observational studies.[34,35] Once the distribution is parameterized, a random value is selected for each transition probability out of the 5,000 iterations and then fed into Equation 3 to derive direct, indirect, and quality of life costs. By incorporating a range of possible values around the key parameters, the end result provides a maximum and minimum value which illustrate a more realistic picture of the economic burden of bladder cancer.

Results

The OCRC team estimated that 199 newly diagnosed bladder cancer cases in 2011 were attributable to occupational exposures. Table 2 details these cases disaggregated by sex and age. As Table 2 makes evident, men have a much higher incidence of occupational bladder cancer compared to women. Men account for 98% of all occupational bladder cancer incidents in 2011 compared to 2% of women. Another noteworthy fact is that the majority of occupational bladder cancer cases arise in the middle age group of 45-49 and after. The two-aforementioned phenomena can be explained by the following: 1) exposure to the carcinogens associated with bladder cancer occurs in male dominated occupations and 2) there is a long latency period between exposure and the onset of bladder cancer. This fact highlights the importance of early prevention strategies to address the onset of bladder cancer later life, an issue we expand upon in the discussion section.

The incidence rate of different stages of bladder cancer at diagnosis is 52% at the Ta stage, 35% at the T1 High grade stage and 13% at the T2/T3/T4 stage for both males and females. At each of these stages there is a relatively higher survival probability compared to some other cancer types such as pancreatic and lung cancer. As a result, health care costs are high since many receive the necessary treatment and survive a prolonged period of time to

receive follow-up care. The five-year survival rate for bladder cancer patients is 32% for men and 28% for women.[23]

Table 2: Total number of bladder cancer by sex and age group

Table 3 provides a breakdown of the economic burden of bladder cancer and the results from the sensitivity analysis. The estimated total societal burden is $131 million CAD or $658,055 CAD per case, with direct costs comprising 6%, indirect costs for 29%, and quality of life costs accounting for 65%. Looking across gender, men account for 98% of the total burden. The age group of 45+ account for 99% of total costs for men and 98% for women. Although survival probabilities factor into direct and indirect costs, the loss of health-related quality of life and its related monetary value represents the largest portion in terms of the burden's estimates. One-way sensitivity analysis was undertaken on the value of $100,000 for QALYs. With this value, the estimated total economic burden of bladder cancer is $216 million compared to $131million at a $50,000 value. To address the potential double counting issue, we subtracted values that may be indirectly captured in the health-related quality of life component, in this case the productivity and output costs. If we excluded these values, then the total burden of bladder cancer would be $93 million dollars, where health-related quality of life accounts for 92% of the total cost. The results from probabilistic analysis provide a range of values with a 95 % confidence interval. The results show that average direct costs per case is $37,973 ($27,316 - $48,610), indirect costs per case is $191, 393 ($176,162 - $206,624), and the health-related costs at $50,000/QALY is $428,689 ($427,753 - $438,047).

Table 3: Total economic costs (2011 Canadian dollars)

Table 4 shows a further breakdown of costs by gender and categories. Looking across the individual category, health care costs represents a majority of costs under direct costs at 2% of the total economic burden or $21,947 per case. This includes costs absorbed by the health care system during the first five-years of treatment and follow-up care. Under indirect costs, loss of income due to morbidity and mortality account for 12% and 18% or $71,562 and $57,095 per case respectively, while 58% of the total costs is attributed to loss of health and function. The breakdown of total costs for female population is provided in supplementary table 3.

Table 4: Total economic costs for male population in 2011

Discussion

The existing studies[2,10] that investigate the economic burden of cancer are limited to only the direct and indirect costs of cancer, which fails to capture the full economic burden of disease accurately. Estimates of new cancer incidences due to occupational exposure are rare since they often require micro and macro-level data from multiple sources in addition to complex epidemiological approaches to estimate the attributable fractions. Our study is the first to estimate the societal-level economic burden of illness associated with occupational bladder cancer of a cohort over the expected treatment and follow-up period of 5 years.

Our estimates include three broad categories of burden – direct, indirect costs, and loss of health and function – along with a life course modelling approach to estimate the prognosis of different stages of bladder cancer. The study also sheds light on the often-neglected category of burden measurement, which is the loss of health-related quality of life attributable to a health condition. This redirects the emphasis of economic burden studies from a focus on market losses and health care costs to losses of health and well-being experienced by individuals.

The total economic burden of $131 million (CAD), and direct costs of $37,973 CAD per case of bladder cancer, with direct health care costs of $21,947 due to occupational exposure is comparable to the health care costs of other cancer types. Similarly, Oliveria et al[36] estimated $22,000 (CAD) for the direct health care costs of bladder cancer and $23,000 (CAD) for all cancer types. Bachir et al[37] also derived a similar estimate of $20,900 for direct health care costs for cancer in their study. The similarity of our findings compared to multiple studies further validates and reinforces our estimates. It should also be noted that our burden estimate is relatively conservative. In particular, for health-related quality of life, which comprised the largest component of the burden, we used a conservative value of $50,000 for QALYs in accordance with other studies,[27] although a value of $100,000 for QALYs was applied for our sensitivity analysis.

This study is the first step toward policy making in the area of preventative cancer care measures. With the comprehensive knowledge of causes and risk factors of bladder cancer, policy makers can take this opportunity to reduce the exposure or eliminate the carcinogens from the workplace altogether. Additionally, due to the long latency before onset, officials might consider implementing early cancer screening efforts, especially for those who are at high risk. The estimates from this study can also serve as input into the evaluation of prevention efforts.

In general, this paper assists policy makers who are seeking to make an evidence-based policy decision about occupational health and safety prevention priorities, as well as provide academics with a methodological approach to estimating other economic burdens of illness. As noted, since there is currently no consensus on how best to include quality of life measures into economic burden estimates, our approach may serve as a starting point for discussion.

Strengths and limitations

Our study makes use of various rich population-level micro- and macro-data sources to estimate the incidence and economic burden of newly diagnosed cases of occupational bladder cancer in Canada in 2011. We are able to stratify by sex, age bracket, and the stage of cancer in order to provide sub-strata details – something that previous studies were unable to accomplish. For example, Brown et al[38] only provided data for under 65 years of age and 65 years of age and older. Our economic burden estimates of occupational bladder cancer, to our knowledge, are the first such study.

Our study uses detailed costing methods and accounted for all resources covered by the universal health care system in Canada, out of pocket costs that are not covered by the universal health care plan, as well as indirect costs. Furthermore, the study considers the value of losses in health-related quality of life associated with occupational bladder cancer rather than just direct and indirect costs. This is an important value which is included in health technology assessment studies but often missing in burden of disease studies. However, recent burden studies are moving in this direction.[17,29-32] We are also more comprehensive in our estimates of indirect costs, including both employer adjustment costs and market output/productivity losses associated with morbidity and premature mortality.

Our study does, however, have a few limitations. We did not obtain accurate out of pocket costs for bladder cancer patients due to the unavailability of the estimates for this group. Instead, we derived the Canadian cancer patient's OOPC spending from Longo et al[22] with an assumption that the costs will be similar across other cancer types. Given that many cancer treatment options are provided outside of the hospital setting, this category of cost may underestimate actual out of pocket costs incurred.

There is also a lack of consensus on the monetary value assigned to health-related QALYs in the health policy arena. This is exemplified by the use of a wide range of monetary values per QALYs in reports and peer reviewed studies. For example, in the USA, a commonly used threshold value was $50,000 per QALY, but this value has been recently updated to $100,000 or $150,000 per QALY based on the recent findings on willingness to pay.[39] In the U.K, a range of £20,000 – £30,000 has been proposed as the approximate threshold value. Canada has considered thresholds of $50,000/QALY since the 1990s and more recently $100,000/QALY but no consensus was achieved of what values to use in health technology assessments. Hence, the results need to be interpreted with caution as the threshold value of QALYs is based on different cultural and social safety net structure of the country. Given the utility value however, one can apply a country-specific threshold value to convert non-health measures to the monetary value of health-related QALYs. Another concern is the possibility of overlap in the QALYs construct and other cost categories included in our analysis. Even though QALYs were designed to capture the value of health in social role functioning and the intrinsic value of health, some academics have raised the concern about possible overlap with productivity and output measures.[40] In order to address the double-counting issue, we excluded the value of indirect costs as an addition to a sensitivity analysis following the method developed by Tompa et al.[16] Our burden estimate is dominated by forgone health-related quality of life associated with bladder cancer; it comprises 61% of the total estimated burden. Thus, even on its own, the health-related quality of life losses from occupational burden cancer are substantial on a per-case basis. Lastly, policy makers and researchers working in the health and safety arena need to be cautious using the results at face value since the economic burden estimates reflect one's lifetime costs and not the annualized costs which are more relevant in the health intervention

field. Nonetheless, our estimates are of value to current industry-wide efforts to reduce occupational exposure and the number of cancer cases in Canada.

Summary and Conclusions

The total burden to Canadian society of newly diagnosed occupational bladder cancer cases in 2011 is $131 million. The per-case average lifetime cost is $658,055 The key components of this burden is as follows: 65% attributable to losses in health-related quality of life; 6% to direct costs, including health care, out of pocket, family care giving and worker's compensation administration, and 29% to indirect costs including lifetime output and productivity in market and home production and employer adjustment costs. This burden estimate is substantial yet it underrepresents the total economic burden of bladder cancer since we only included new cases in 2011. Our findings can be useful in flagging the magnitude and number of bladder cancer incidences, mobilizing key interest groups and policy makers in the areas of cancer prevention, and for setting more comprehensive work and safety standards in the future.

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Table 1: List of Carcinogens linked to Bladder Cancer

Type of Exposure/Activity	Carcinogen	Level of Evidence
Chemicals and mixtures	Aromatic amines	Sufficient
Chemicals and mixtures	Diesel engine exhaust	Limited
Chemicals and mixtures	Polycyclic Aromatic Hydrocarbons and related products	Limited
Aluminum production		Sufficient
Painting		Sufficient
Rubber production		Sufficient
Hairdressers and barbers		Limited
Tetrachloroethylene		Limited

Table 2: Total number of bladder cancer by sex and age group

Sex	Age bracket	Attributable cancer	Estimated number of cases in 2011	Sex	Age bracket	Attributable cancer	Estimated number of cases in 2011
M	15 - 19	0.00%	0.000	F	15 - 19	0.00%	0.000
M	20 - 24	0.00%	0.000	F	20 - 24	0.00%	0.000
M	25 - 29	0.19%	0.019	F	25 - 29	0.02%	0.001
M	30 - 34	0.65%	0.097	F	30 - 34	0.07%	0.003
M	35 - 39	1.14%	0.228	F	35 - 39	0.12%	0.006
M	40 - 44	1.77%	0.798	F	40 - 44	0.18%	0.035
M	45 - 49	2.36%	2.474	F	45 - 49	0.21%	0.096
M	50 - 54	2.64%	6.728	F	50 - 54	0.24%	0.265
M	55 - 59	3.43%	13.563	F	55 - 59	0.29%	0.450
M	60 - 64	3.27%	22.250	F	60 - 64	0.25%	0.429
M	65 - 69	5.51%	44.623	F	65 - 69	0.28%	0.636
M	70 - 74	4.81%	42.537	F	70 - 74	0.22%	0.524
M	75 - 79	3.65%	34.289	F	75 - 79	0.14%	0.390
M	80 - 84	2.40%	19.654	F	80 - 84	0.08%	0.214
M	85+	1.26%	8.785	F	85+	0.04%	0.127
Total cases			**196.050**				**3.182**

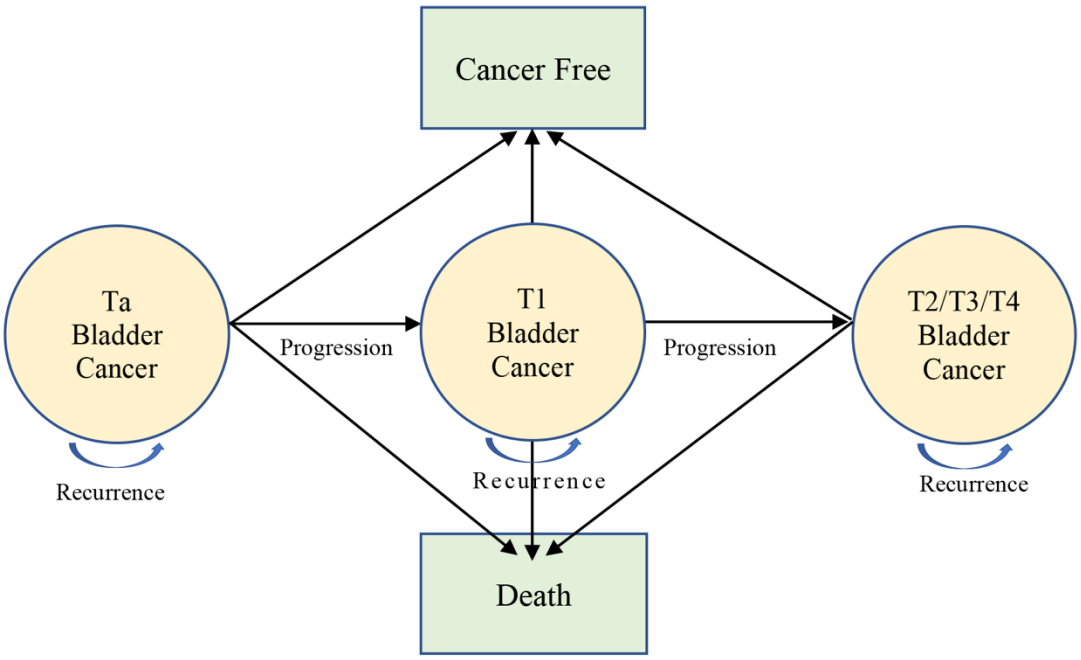
Table 3: Total economic costs (2011 Canadian dollars)

Sex	Age group at diagnosis	Attributable occupational cancers	Direct costs	Indirect costs	Health related costs at 50k	Health related costs at 100k
Both	25 to 29	0	10	$13,170	$24,168	$48,335
Both	30 to 34	0	$3,870	$68,856	$112,383	$224,766
Both	35 to 39	0	$8,970	$166,359	$238,863	$477,727
Both	40 to 44	1	$31,918	$571,235	$762,549	$1,525,098
Both	45 to 49	3	$98,381	$1,723,153	$2,111,308	$4,222,615
Both	50 to 54	7	$267,598	$4,001,616	$5,074,719	$10,149,438
Both	55 to 59	14	$536,199	$6,382,663	$8,887,777	$17,775,554
Both	60 to 64	23	$866,674	$7,216,982	$12,567,839	$25,135,677
Both	65 to 69	45	$1,729,193	$7,480,749	$21,190,145	$42,380,289
Both	70 to 74	43	$1,645,178	$4,853,029	$16,853,649	$33,707,297
Both	75 to 79	35	$1,298,808	$3,351,883	$11,189,691	$22,379,382
Both	80 to 84	20	$744,087	$1,651,247	$5,199,265	$10,398,531
Both	85+	9	$333,880	$650,675	$1,196,218	$2,392,437
Total		**199**	**$7,565,527**	**$38,131,617**	**$85,408,573**	**$170,817,147**
Average per case			$37,973	$191,393	$428,689	$658,055
High per case			$48,630	$206,624	$438,047	$693,301
Low per case			$27,316	$176,162	$427,753	$631,231

Table 4: Total economic costs for male population in 2011

Sex	Age group at Diagnosis	Healthcare Costs	Informal Caregiver Costs	Out of Pocket Costs	Friction Costs	Total Productivity Costs (morbidity)	Fringe Benefit	Total Mortality Costs	Household Production	QALY Morbidity Losses	QALY Mortality Losses	Total Lost QALYs	Estimating $50k/QALY	Estimating $100k/QALY
Male	25 to 29	$419	$341	$310	$496	$3,131	$120	$8,637	$160	0.01	0.46	0.47	$23,297	$46,594
Male	30 to 34	$2,144	$1,726	$1,585	$2,912	$17,622	$702	$43,951	$981	0.04	2.15	2.19	$109,732	$219,463
Male	35 to 39	$5,017	$4,067	$3,709	$7,328	$48,967	$1,878	$99,674	$2,758	0.11	4.59	4.69	$234,726	$469,453
Male	40 to 44	$17,518	$13,698	$12,951	$26,442	$181,754	$6,446	$321,785	$11,542	0.35	14.47	14.83	$741,252	$1,482,504
Male	45 to 49	$54,298	$43,147	$40,142	$84,796	$639,864	$21,986	$866,775	$42,806	1.07	40.17	41.24	$2,062,028	$4,124,057
Male	50 to 54	$147,662	$119,946	$109,166	$226,318	$1,584,143	$54,793	$1,818,817	$138,971	2.89	96.33	99.22	$4,961,038	$9,922,076
Male	55 to 59	$297,687	$239,055	$220,080	$439,552	$2,726,389	$109,584	$2,455,553	$332,797	5.51	169.13	174.64	$8,731,854	$17,463,707
Male	60 to 64	$488,341	$390,193	$361,031	$656,481	$3,086,379	$155,284	$2,231,736	$642,547	9.13	239.94	249.06	$12,453,246	$24,906,492
Male	65 to 69	$979,366	$781,043	$724,047	$965,782	$2,827,130	$227,700	$1,883,376	$749,673	17.05	404.31	421.36	$21,067,795	$42,135,590
Male	70 to 74	$933,584	$740,557	$690,200	$728,868	$1,493,705	$188,302	$858,456	$813,336	15.03	320.75	335.79	$16,789,293	$33,578,586
Male	75 to 79	$752,571	$601,102	$530,344	$534,953	$910,297	$133,293	$424,211	$727,031	10.95	212.34	223.29	$11,164,364	$22,328,728
Male	80 to 84	$431,357	$351,133	$303,981	$269,291	$374,995	$68,295	$139,055	$437,084	4.28	99.61	103.89	$5,194,539	$10,389,078
Male	85+	$192,812	$154,175	$135,876	$98,952	$135,292	$23,711	$41,481	$190,632	1.56	22.36	23.92	$1,195,877	$2,391,754
TOTAL		**$4,302,775**	**$3,440,184**	**$3,133,425**	**$4,042,172**	**$14,029,668**	**$992,095**	**$11,193,507**	**$4,090,316**	**67.99**	**1626.59**	**1694.58**	**$84,729,041**	**$169,458,081**
Per Case		$21,947	$17,547	$15,983	$20,618	$71,562	$5,060	$57,095	$20,864				$432,180	$864,361
Proportion		0.0190	0.0153	0.0139	0.0220	0.1187	0.0054	0.1822	0.0452				0.5782	

Figure 1: Markov model for bladder cancer



Appendix 1: Costs by key stakeholder group

	Individual	Family & Community	Employer	System & Public Sector	Society
1. Direct	• out-of-pocket expenses for healthcare products & services	• informal care giving of family & community members	• insurance programs costs for healthcare products & services and related administrative costs	• healthcare products & services and related administrative costs	Individual + Family & Community + Employer + System & Public Sector
2. Indirect	• *labour-market earnings* • payroll benefits associated with labour-market earnings • wage replacement benefits • home production	• *family income/savings* • *quality of life of family and community members* • *adult outcomes of children*	• friction costs • insurance program costs for wage replacement benefit and related administrative costs • *labour relations and reputation*	• productivity & output • *capital accumulation, investment, and related productivity implications*	
3. Quality of life	• engagement in social roles • intrinsic value of health				

Supplementary Table 1: Parameter estimates in the base-case analysis

Procedure	Unit cost	Range	Source	Mean cost per patient (2011)
Pre-urologist consultations				
Physician fees	$50.00	15.2 - 94.4	Bladder cancer cohort	$1,299
Post-urologist consultation				
Urologist Consultation	$50.00	15.2 - 94.4	Bladder cancer cohort	$1,038
Cystoscopies				
Physician fees	$50.90		RAMQ reimbursement act code list	$37
Procedure fees	$192.20		Quebec MSSS	
Urinary cytology	$87.00		MUHC administration	
Trans-Urethral Resection of a Bladder Tumor (TURBT)				
Physician fees	$208.00		RAMQ reimbursement act code list	
Hospitalization	$1,371.00		Quebec MSSS	
Anesthesia physician fees	$150.00		RAMQ reimbursement act code list	
Pathology report imaging	$40.00		MUHC administration	
Physician fees	$45.00	16.5 - 200	Bladder cancer cohort	
Radical cystectomy				
Physician fees	$1,880.00		RAMQ reimbursement act code list	
Hospitalization	$14,855.00		RAMQ reimbursement act code list	$18,979
Anesthesia physician fees	$1,160.00		RAMQ reimbursement act code list	
Pathology report imaging	$450.00		MUHC administration	
Post-surgery				

Post-operative consultation	$50.00	15.20 - 94.40	Bladder cancer cohort	$635
Physician fees	$45.00	16.9 - 45.6	Bladder cancer cohort	$579
Hospitalization	$1,371.00		Quebec MSSS	$2,076

- Régie de l'assurance maladie du Québec (REMQ), McGill University Health Centre (MUHC)

Supplementary Table 2: Utility value in the base-case analysis

Utilities	Values	SE	Source
Cystectomy	0.80	0.160	Bachir et al., (2014)
Gastrointestinal complication after cystectomy	0.97	0.194	Bachir et al., (2014)
Genitourinary complication after cystectomy	0.93	0.186	Bachir et al., (2014)
Metastases responsive to chemotherapy	0.62	0.124	Bachir et al., (2014)
Metastases unresponsive to chemotherapy	0.30	0.006	Bachir et al., (2014)
Surveillance cystoscopy	0.99	0.050	Bachir et al., (2014)
Chemotherapy	(0.36)	0.060	Bachir et al., (2014)
Chemotherapy complication	(0.54)	0.072	Bachir et al., (2014)
Cystectomy complication	(0.30)	0.060	Bachir et al., (2014)
TURBT	(0.10)	0.020	Bachir et al., (2014)

- Values in bracket reflect negative utility associated with treatment

Supplementary Table 3: Total economic costs for female population in 2011

Sex	Age group at Diagnosis	Attributable Occupational Cancers	Healthcare Costs	Informal Caregiver Costs	Out of Pocket Costs	Friction Costs	Total Productivity Costs (morbidity)	Fringe Benefit	Total Mortality Costs	Household Production	QALY Morbidity Losses	QALY Mortality Losses	Total Lost QALYs	Estimating $50k/QALY
Female	25 to 29	0.001	$25	$8	$16	$13	$61	$3	$193	$8	0.00	0.02	0.02	$871
Female	30 to 34	0.0034	$83	$26	$58	$42	$229	$11	$620	$33	0.00	0.05	0.05	$2,652
Female	35 to 39	0.006	$147	$46	$96	$78	$451	$19	$1,025	$70	0.00	0.08	0.08	$4,137
Female	40 to 44	0.0355	$870	$282	$578	$445	$2,757	$113	$5,477	$493	0.00	0.42	0.43	$21,297
Female	45 to 49	0.0963	$2,361	$742	$1,580	$1,216	$7,302	$306	$12,625	$1,588	0.01	0.98	0.99	$49,279
Female	50 to 54	0.2655	$6,508	$2,007	$4,261	$3,353	$19,948	$854	$27,280	$5,186	0.02	2.26	2.27	$113,681
Female	55 to 59	0.4509	$11,053	$3,480	$7,379	$5,810	$26,743	$1,407	$31,946	$10,347	0.03	3.09	3.12	$155,923
Female	60 to 64	0.429	$10,516	$3,251	$6,785	$5,438	$15,955	$1,362	$16,951	$11,404	0.02	2.27	2.29	$114,592
Female	65 to 69	0.6369	$15,613	$4,944	$10,168	$8,128	$10,303	$1,993	$11,048	$9,628	0.04	2.41	2.45	$122,350
Female	70 to 74	0.5244	$12,855	$4,029	$8,539	$6,671	$4,472	$1,633	$4,149	$8,851	0.02	1.27	1.29	$64,356
Female	75 to 79	0.3908	$9,580	$2,984	$6,313	$4,918	$2,659	$1,219	$2,099	$7,117	0.01	0.49	0.51	$25,327
Female	80 to 84	0.2149	$5,268	$1,651	$3,481	$2,771	$1,269	$689	$905	$4,109	0.00	0.09	0.09	$4,726
Female	85+	0.1274	$3,123	$987	$2,069	$1,622	$596	$403	$442	$2,383	0.00	0.01	0.01	$341
TOTAL		**3.18**	**$78,002**	**$24,438**	**$51,325**	**$40,503**	**$92,745**	**$10,010**	**$114,761**	**$61,219**	**0.15**	**13.44**	**13.59**	**$679,533**

Chapter 3. Impact of Cancer Diagnosis on Labour Market Earnings: Longitudinal Study

Preface

Following on the previous chapter, this chapter continues with the investigation on the economic impact of cancer. Using linked administrative datasets, we set out to estimate the change in labour market earnings of Canadian workers with cancer, by cancer type, over a span of 5 years from the moment of diagnosis.

I, Young Jung, was responsible for conceptualizing the research questions, design, and completing data analysis. Dr. Emile Tompa provided input on research questions and approaches to methodological outlines and research design. Research design, analyses, and interpretations of the study's findings occurred through ongoing conversation with Drs. Emile Tompa, Christopher Longo, and Philip DeCicca. I drafted this thesis chapter, and Drs. Emile Tompa, Christopher Longo and Philip DeCicca provided feedback on draft, which was incorporated into the final version. These analyses were undertaken using micro datasets housed in FRDC at Statistics Canada, in Ottawa, Canada.

Ch.3. Impact of Cancer Diagnosis on Labour Market Earnings: A Longitudinal Study

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Abstract

Objective: To estimate change in labour market earnings due to cancer diagnosis stratified by cancer type and age category.

Methods: The study utilizes Statistics Canada's administrative linkage file which includes microdata from the 1991 Census, the Canadian Cancer Registry, mortality records, and personal income tax files. The empirical strategy used a combination of the Mahalanobis' distance and propensity score matching method and the difference-in-difference regression method to select a control group that is similar to the cancer survivors of our study, and to draw a causal influence of the cancer diagnosis on labour market earnings respectively.

Results: The results showed negative effects of cancer on labour market earnings. Additionally, we found an association between the severity of cancer and labour market earnings, where cancer survivors with a severe type of cancer in terms of the 5-year survival rate are shown to have a larger and more persistent earnings difference compared to the control group.

Conclusions: We found statistically significant labour market earnings losses for the cancer survivors. Improving our understanding of the loss of labour market earnings due to cancer diagnosis and by cancer type plays an important role in starting a dialogue in future policy initiatives to mitigate the burden faced by cancer survivors.

Introduction

Each year, Statistics Canada estimates the recent data on cancer incidence, mortality, and survival rates based on information from the Canadian Cancer Registry and Vital Statistics. A total of 79,000 cancer-related deaths were recorded in 2016 (Statistics Canada Cansim Table 13-10-0393-01), and when deaths are aggregated by age, cancer surpasses heart disease as the leading cause of death (approximately 51,000 per year) since the start of the record period in the year 2000. Based on Statistics Canada's estimates, about 200,000 Canadians are diagnosed with cancer every year, and nearly 1 in 2 Canadians may be diagnosed with cancer during their lifetime.

With recent advancements in early screening and medical technologies, death from all cancers combined has decreased by 1.5% per year, and the 5-year survival rate for all cancer types combined has continued to increase from 49% in 1975 to 67% in 2007 (American Cancer Society, 2017; CDC, 2017), which implies that today more cancer survivors live through the consequences of a cancer diagnosis than in the past. The Canadian Cancer Society (2018) estimated that there were 810,045 Canadians alive in 2009 who were diagnosed with cancer in the previous 10 years, which is the equivalent of 2.4% of the Canadian population. As more individuals with cancer survive and return to their daily lives, the focus of cancer research has shifted from clinical settings to the everyday lives of cancer survivors, including the short-, medium- and long-term labour market outcomes and the income[1] trajectories of cancer survivors.

There is a substantial body of literature that shows change in labour market outcomes due to cancer diagnosis. Breast cancer has so far received the most attention in this literature, partly

[1] Income refers to the unit of analysis of published literature, whereas labour market earnings refer to the unit of analysis of our study. A full description of the labour market earnings is provided in Section 3.3.

because it is the most common type of cancer, and breast cancer has higher survival rates compared to other types of cancer. Among the recent literature, Bradley et al. (2005) and Moran et al. (2011) looked at breast cancer survivors' labour outcomes after a cancer diagnosis. Using a 2-stage model, Bradley et al. (2005) found that breast cancer survivors were 17 % less likely to be employed shortly after the diagnosis (within 6 months) but found no negative effect on labour outcomes at 1 year following diagnosis. Using a longitudinal study, Moran et al. (2011) found that the breast cancer survivors had lower labour market incomes, which persists up to 6 years after the initial diagnosis.

Though a number of other studies have found significant income loss among individuals with cancer, our study contributes to the body of existing literature estimating the impact of cancer diagnosis on labour market earnings. It addresses the limitations of the previously published literature in the following ways. First, our study estimated the short-, mid- and long-term effects of a cancer diagnosis on cancer survivors' labour market earnings. Due to data limitation, most of the previous literature has focused on the short-term consequences of a health shock. This approach, however, hides the long-lasting effects of a cancer on labour market earnings after the completion of treatment, which may influence one's decision to return to work and one's capacity to earn (Tompa et al., 2017). Secondly, in contrast to most of the existing literature, our study only considers individuals who are newly diagnosed with cancer, drawing on the International Classification of Disease -10 information derived from the Canadian Cancer Registry (CCR) combined with administrative and longitudinal annual labour market earnings from the Canadian income tax records, known as the T1 income file. This data source allowed us to investigate changes in post-diagnosis labour market earnings stratified by objectively identified cancer types and the heterogeneity of labour market earning by cancer type. Lastly, we utilized the Mahalanobis'

distance and propensity score matching method to isolate and draw a causal inference of the impact of cancer on cancer survivors' labour market earnings.

Our objective was to determine the impact of cancer diagnosis on the annual labour market earnings of cancer survivors from the moment of diagnosis. We hypothesized that cancer survivors would show persistently significant labour market earnings losses compared to the individuals who are never diagnosed with cancer, and the magnitude of labour market earnings losses would be correlated with the severity of cancer.

Our paper is organised as follows. Section 3.2 provides a detailed literature review. Section 3.3 describes the longitudinal datasets used in the analyses and rationale for selecting control and outcome variables. Section 3.4 discusses the methodology. The results from the study are discussed in Section 3.5, followed by a discussion of our findings in Section 3.6.

Literature Review

In recent years there has been a rapid increase in the number of articles that explore the relationship between cancer diagnosis, labour market outcomes, and subsequent income loss for individuals with cancer. Examples include Andersen et al. (2015); Benth, Dahl, and Luras (2014); Bradley et al. (2002, 2005, 2007); Chirikos et al. (2002); Hauglann et al. (2012); Hopkins et al. (2010); Jeon (2017); Lauzier et al. (2013); Mathews et al. (2009); Moran et al. (2011); and Syse, Trelit, and Kravadl (2008).

Among the recent studies that investigated the impact of cancer diagnoses on labour outcomes and income, breast cancer received the most attention, which is understandable given that this group represents one of the four most commonly diagnosed cancer types (CDC, 2017) and has the highest 5-year survival rate (American Cancer Society, 2017). The optimistic prognosis

of breast cancer provides a cohort of cancer survivors that enables researchers to follow and observe changes over an extended follow-up period.

Focusing on individuals diagnosed with breast cancer, Bradley et al. (2002) have found that breast cancer survivors were approximately 9% less likely to work, a slightly negative labour market earnings difference from women who had no history of cancer. A more recent study (Bradley et al., 2005) that looked at breast cancer survivors has also drawn a similar conclusion that women with breast cancer were about 17% less likely to be employed 6 months following the diagnosis when compared to the individuals without cancer. Chirikos et al. (2002) have found that 41% of the women who return to work required special accommodations to perform daily routines of the job. The authors also found that breast cancer survivors experienced a decline in total hours worked, resulting in income loss.

For men, many studies have also found a decrease in labour market attachment among prostate cancer survivors. Mathews et al. (2009) have found that men with prostate cancer were less likely to be working 6 months following the diagnosis when compared to individuals who had never been diagnosed with cancer. Bradley, Neumark, Luo, and Schenk (2007) have found that men who went through prostate cancer treatment experienced reduced ability to perform certain physical and cognitive tasks once they returned to work. Furthermore, the authors found that men with prostate cancer were 10% less likely to be working at 6 months following diagnosis when compared to those without prostate cancer.

When a longer post-diagnosis follow-up period was considered, Bradley et al. (2007) found little to no evidence of negative effects of cancer on labour outcomes after following the individuals with breast cancer for 12 to 18 months. A more comprehensive study (Moran et al., 2011) that included all types of cancers found that cancer survivors had lower employment rates

(12% decrease) and also fewer working hours (3.4 hours per week for female survivors and 5.5 hours per week for male survivors) compared to individuals with similar characteristics over a 6-year follow-up period.

In the Canadian setting, Lauzier et al. (2013) followed 829 individuals with breast cancer in Quebec, Canada, and found that income loss along with out-of-pocket costs due to cancer were the driving factors for the deterioration in a family's financial situation. Furthermore, the authors found that 21.6% of the cancer survivors did not return to work 12 months following the initial diagnosis. Using a Canadian administrative dataset, Hopkins et al. (2010) found a decrease of 36% of labour force participation following a cancer diagnosis, which resulted in a loss of $4,987 (26.5%) of annual household income. Jeon (2017) have used linked administrative datasets, which enabled the authors to follow working-age individuals with cancer for up to 5 years. The author found that, on average, individuals with cancer earn $5,078 or 12% less than the non-cancer group, 2–6 years post-diagnosis. Using the longitudinal nature of the datasets, the study also found an inverse relationship, where the negative effects of the cancer diagnosis decreased as the individuals are further removed from the moment of the cancer diagnosis.

Amongst European studies, Andersen et al. (2015) found a small but persistent income loss (approximately DKK 6000 to 9000) among individuals with breast cancer in Denmark, even 3 years after the initial diagnosis. Hauglann et al. (2012) followed individuals with breast cancer over 9 years and observed the largest income loss in the first 2 years after diagnosis. However, applying the authors' definition of significant income loss (greater than 10% of pre-cancer income), the negative impact of cancer diagnosis on income became negligible at the 5-year follow-up period. A long-term follow-up study by Benth, Dahl, and Luras (2014) found that individuals with breast cancer suffer persistent income loss (approximately €7,270) even 13 years

after diagnosis. A more comprehensive study conducted by Syse, Trelit, and Kravadl (2008) found a correlation between the magnitude of income loss and the severity of cancer. For example, a skin cancer diagnosis was shown to have a positive income loss, meaning that individuals with skin cancer did not suffer any income loss, but instead went on to earn higher incomes after diagnosis compared to the individuals without cancer. Individuals with more severe cancer types, such as lung and brain cancer, exhibited 49.3% and 45.4% decrease in incomes, respectively, compared to the individuals without cancer.

While previous studies have demonstrated that cancer diagnoses result in decrease in labour force participation in terms of hours worked and earnings, they suffer from four important limitations. First, the average decrease in income across all age groups may conceal significant changes in labour market earnings and labour market attachment, particularly for those of "active" working age (25–54) and in the "less-active" working age group (55+), a labour force description defined by Statistics Canada (National Household Survey, 2011). Second, the short follow-up period provides little information on the mid- and long-term earnings trajectories of individuals. Third, the narrow focus on a few cancer types (primarily breast and prostate cancer) provides no insights into other cancer types that have a poor prognosis. Particularly, we want to determine whether there will be any differences in labour market earnings for individuals with cancer by low vs. high 5-year survival rates. Lastly, many of the previous studies used population-based surveys, which lack detailed information on cancer type, severity, and the annual income of the afflicted individuals, so they often suffer from a small sample size. Thus, they may not be an accurate representation of the cancer survivors and their labour market earnings loss due to a cancer diagnosis.

Despite the growing number of studies that investigate the impact of a cancer diagnosis on labour market outcomes, more research is needed on the long-term impact of cancer. In this study, we estimated the impact of cancer on cancer survivors' labour market earnings using a unique dataset that linked several Canadian administrative and survey datasets. We considered individuals diagnosed with different cancer types separately and assessed how the individuals' labour market earnings changed over time between the "active" (25–54 years old) and "less-active" (55 years and older) working groups.

Data

We used the 1991 Canadian Long-form Census Health and Environment Cohort (CanCHEC) dataset. It is a unique dataset that combines data from five administrative sources: Canada's 1991 Census of Population, the Canadian Mortality Database (CMDB), the Canadian Cancer Database (CCDB), Canadian Cancer Registry (CCR), and the T1 Family File (T1FF). A full description of each of the data sources is provided in Appendix 1.

The 1991 Long-form Census of Population served as a foundation for our analysis. The long-form census contains information which includes individuals' sociodemographic characteristics, such as disability status, educational attainment, household size, immigrant status, self-employment, sex, and visible minority status. The long-form census includes 25% of all Canadians aged 25 years and older as of June 4, 1991. A record linkage was undertaken by Statistics Canada of the census cohort with the 1990/1991 individual tax file records. The initial phase of the linkage was performed by the microdata linkage division at Statistics Canada, hence a more detailed description of the methodology can be found in Wilkins et al. (2008). The data custodians selected personal information from Canadian Cancer Registry (CCR), Canadian Cancer Database (CCDB), and Canadian Mortality Database (CMDB) and merged them across the

individual records to create a subset of the data containing demographic characteristics, cancer diagnoses, cancer survivorship, and death records in a longitudinal form. The final CanCHEC dataset represents approximately 2.5 million Canadians over the age of 25 from 1991 and follows them from that year onwards. The CanCHEC dataset was used to identify new cancer diagnoses and previous cancer histories. It also allows us to follow individuals with cancer from diagnosis onward from 1992 until 2013. Figure 1 provides an overview of the dataset.

[Insert Figure 1 here]

The outcome of interest: Annual and percent change in annual labour market earnings

Annual labour market earnings consist of multiple items that are drawn from the annual income tax files. We defined total annual labour market earnings as incomes from T4 slips (line 101), commission and tips-based income (T1 line 102), and net self-employment income (T1 line 135, 137, 139, 141, 143). As the second unit of analysis, a percent (%) change in annual labour market earnings was also be estimated to highlight the relative change in labour market earnings between the cancer survivors and the control group (individuals without cancer). A total of 8 years of tax records were linked to both individuals with and without cancer: 2 previous years with labour market earnings before the cancer diagnosis ($t\text{-}1$,$t\text{-}2$), the diagnosis year ($t=0$), and 5 years after the diagnosis ($t=1,\ldots,5$).

Control Variables

We selected controlling variables based on the previously published cancer literature, discussed in the literature review section, with consideration for the relationship between annual labour market earnings and sociodemographic variables. The selected control variables include time-varying

variables (age, household size) and time-invariant variables (highest educational attainment, immigrant status, sex, and visible minority status).

Time-varying control variables

Age is coded as a continuous variable, and it is pertinent to control for the age profile of our sample since there is an abundance of research (Claus et al., 1990; Morris et al., 2008) that identifies the relationship between age and the onset of cancer. Household size refers to the total number of household members that are reported on the annual family income data. Based on the equivalent scale used by Statistics Canada (2010), the oldest person in the family was assigned a factor of 1.0, the second oldest person in the family was assigned a factor of 0.4, and the other family members under age 16 were assigned a factor of 0.3

Time-invariant control variables

It is important to control for disability status, as evidence suggests that individuals who identify as disabled are more likely to have a lower level of educational attainment and less likely to be engaged in the labour market (Roth et al., 2001). Thus, they tend to have lower labour market earnings compared to non-disabled individuals. Disability status is coded 1 if an individual is disabled and 0 otherwise. Educational attainment is estimated using a series of dummy variables: less than high school, high school, some university/college, and university and higher. Visible minority status is coded as 1 for visible minority and 0 for a non-visible minority. The inclusion of visible minority status in our model will enable us to control for the socio-cultural differences between visible and non-visible minority populations in terms of labour market engagement and family support.

Sample construction and characteristics

Our main objective is to estimate the change in labour-market earnings over a span of 5 years amongst cancer survivors with newly-diagnosed cancer across two different age groups: 25–54 and 55+. We identified newly-diagnosed cancer cases using ICD-3-O and ICD-3-H information from the Canadian Cancer Registry (CCR) starting in 1992. In order to ensure that our cancer sample consisted of individuals with newly-diagnosed cancer, we considered information from the linked CCDB dataset, which contains all previous cancer records between 1963 and 1991. This allowed us to remove any individual with a previous history of cancer. Starting with the calendar year 1992, only new cases of cancer with no history of cancer were retained over the following 5 years. This process was repeated annually until 2008. In total, we identified 85,182 individuals with newly-diagnosed cancer from 1992 to 2008.

Once the individuals with newly-diagnosed cancer were identified, those individuals who had a labour market attachment (i.e., reported labour market earnings greater than 0) in the 2 years prior to their cancer diagnosis were included in our study in order to estimate the change in labour-market earnings due to cancer diagnosis. Additionally, our sample included only those who were above the age of 25, since this age group is the start of what is considered the active working age (i.e., 25–54) by Statistics Canada (National Household Survey, 2011). A follow-up period of 5 years for the cancer group was decided based on clinical guidelines (Jayne et al., 2010; Sagawa et al., 2017) in order to ensure comparability with previously published studies. Additionally, it is only after a 5-year remission period that individuals with cancer may be considered cancer-free (Jayne et al., 2010; National Cancer Institute, 2018; Sagawa et al., 2017). As the last step of the sample selection, we removed anyone who had a recurrence of cancer or died during the follow-up period. In total, the above-mentioned selection criteria resulted in the exclusion of 19,631, 770,

and 5,249 individuals respectively. A visual depiction of the selection process can be found in Figure 2.

[Figure 2 Cancer group selection process]

Following the sample selection process described above, there were 59,532 newly-identified cancer cases (30,956 men and 28,576 women) at the time of diagnosis for individuals aged 25 and over who were alive at least 5 years after the initial cancer diagnosis. The distribution of all cancer types identified using the CCR database is shown in Table 1.

[Insert Table 1 here]

The most prevalent cancer type is prostate cancer, representing 17.96% of the sample, followed by breast cancer at 14.56%. We compared the proportion of cancer types in our sample with published reports from the Canadian Cancer Society (2018) and found that our distribution was similar to the published literature. Despite having access to extensive lists of cancer types, we noticed that rare types of cancers such as nasal cavity, ear, and spinal cord cancer provided small sample sizes, which restricted the power of our analysis. Therefore, we included 12 different types of cancers in alignment with the most representative cancer types in Canada (Canadian Cancer Society, 2018) and regrouped them as follows: all cancers (includes 23 different cancer types identified in our study), 4 major cancer types, and 12 cancer types. Lung, Colorectal, Breast and Prostate cancers were included as the 4 major types. The proportions of the sample that comprised the 4 cancer types are as follows: breast cancer represents 14% of the cancer observations, prostate cancer is at 18%, lung cancer represents 13%, and colorectal represents 13%. Selection of the 12 cancer types was based on a cut-off point of at least 2% of the total sample as well as the published cancer report on the distribution of cancer in Canada (Cancer Care Society, 2017). The 12 types

included: breast, bladder, blood, cervix, colorectal, esophagus, kidney, lung, pancreas, prostate, skin, and thyroid.

[Insert Table 2 here]

Table 2.2 shows that a majority (over 75%) of new cancer diagnoses occur in the age group of 50 and up. This finding aligns with the recent Canadian Cancer Report (Canadian Cancer Statistics, 2018) that found the incidence rate of cancer is positively related to age for all cancers.

Methodology

We considered two econometrics methods to estimate and isolate the impact of a cancer diagnosis on labour market earnings. One potential strategy is to apply the Fixed Effect (FE) model to use changes in health status (i.e., cancer diagnosis) within individuals as a way to control for hard-to-measure time-invariant individuals' factors that would be correlated with both exposure and labour market earnings. However, when the time-varying confounders such as individuals' motivation to participate in the labour force and the capacity to work are changing concurrently with the cancer diagnosis, the estimates derived from using the FE model may not be valid. The desire to control for these time-varying confounders lead us to identify the counterfactual group using the Mahalanobis' distance and propensity score matching and estimate the impact of cancer diagnosis on labour market earnings using the difference-in-difference model.

The Mahalanobis' distance and propensity score matching

We followed the work by Tompa et al. (2010) to match individuals newly diagnosed with cancer to similar individuals without cancer to serve as controls[2]. The average effect of a cancer diagnosis on an individual's labour market earnings can be represented as follows:

$$y_{i,t+s}^{1} - y_{i,t+s}^{0} \tag{1}$$

where y indicates annual labour market earnings, superscript 1 indicates that an individual is diagnosed with cancer, 0 indicates a matched control individual without cancer, and subscript t+s refers to time.

The above equation (1) can also be depicted in more detail as follows:

$$E\{y_{t+s}^{1} - y_{t+s}^{0} | \, T_{it} = 1\} = E\{y_{t+s}^{1} | T_{it} = 1\} - \, E\{y_{it}^{0} | T_{it} = 1\} \tag{2}$$

where $T_{it} \in \{0,1\}$ refers to whether an individual *i* is diagnosed with cancer (*T*=1) or not (*T*=0) in the time period *t*. y_{t+s}^{1} is the annual labour market earnings at time *t+s* following cancer diagnosis.

The empirical challenge is to construct the counterfactual, the last term in equation (2), the expected annual labour-market earnings of individuals had they not been diagnosed with cancer. Additionally, in the observational study with no randomization, individuals with cancer often differ systematically from individuals without cancer. Thus, an unbiased estimate of the cancer diagnosis effect on labour market earnings could not be obtained by directly comparing the outcomes between the two groups.

One way that this estimation issue can be resolved is by using the Mahalanobis' distance and propensity score matching. The importance of propensity scores and their application is

[2] For ease of description after the sample selection, the cancer survivors refer to the individuals with cancer who are alive over the follow-up period of 5 years, and the control group refers to individuals without cancer

discussed by Rosenbaum and Rubin (1973a, 1973b) who introduced the propensity score theorem. Angrist and Pischke (2009, p173.) compared the propensity score theorem to the omitted variable bias formula for regression in stating that "the propensity score theorem says that you only need to control for the covariates that affect the probability of treatment." The main point is that we can use observational data to match the individuals with cancer to those without cancer, and if the matching is done properly, two individuals (i.e., one with cancer and one without cancer) with the same propensity score are identical except for their treatment status (i.e., cancer) and they can be considered as randomly assigned to each group. Using the matching technique, we are able to construct a sample of the control group that is identical to the cancer survivors to approximate the non-observed counterfactual event in the last part of the equation (2).

To implement the Mahalanobis' distance and propensity score matching, a model for the probability of an individual getting diagnosed with cancer is required. We began by estimating the probability of being diagnosed with cancer (or propensity score) using a logit model:

$$p(T_{it} = 1) = F(X_{i,t-2}, D_j, D_t) \tag{3}$$

where $T_{it} = 1$ indicates an individual who has no prior history of cancer, but who is diagnosed with cancer in year *t=0*. $X_{i,t-2}$ represents an individual's pre-cancer characteristics: age, disability status, household size, highest educational attainment, sex, immigrant status, 2 previous years of labour market earnings and visible minority status. D_j, D_t control for time-invariant fixed effects and time effects respectively. The Mahalanobis distance was estimated using the equation (4) as follows,

$$D_{ij} = \left(X_i - X_j\right)' \sum^{-1} \left(X_i - X_j\right) \tag{4}$$

where $\sum$ is the variance of covariance matrix of X.

Traditional methods of matching using propensity scores involve estimating propensity scores from a pool of covariates. However, this approach prevents the use of a number of dimensions that may provide for a more precise match. For instance, a 50-year-old male cancer survivor could be matched to a 55-year-old female non-cancer individual under the traditional approach. Instead of using a pooled sample and covariates to estimate propensity score, we followed the work by Tompa et al. (2010) in order to create more precise match by implementing the following steps: First, we divided the samples by sex for each calendar year between 1992 and 2008. In the second step, we divided the male and female survivors into 9 age groups: 25 to 29, 30 to 34, 35 to 39, 40 to 44, 45 to 49, 50 to 54, 55 to 59, 60 to 64, and 65+. Thirdly, we randomized the order of the observations before estimating propensity scores and the subsequent matching. Lastly, we applied many-to-one matching with no replacement option, and caliper widths that are 0.25 of the pooled standard deviation of the logit of the propensity score (Rosenbaum and Rubin, 1983). Hence, the absolute value of the difference between the cancer survivors and the control group's propensity scores was minimized. This was a more rigorous method as it did not employ global minimization of the difference in propensity scores. This ensured that a 50-year-old male cancer survivor would be matched with a 50-year-old male non-cancer individual, and that the sorted order of the observations did not influence our matched non-cancer group.

Using the propensity scores, matches were chosen for each cancer case one at a time, and at each step an individual without cancer was selected that had not yet been matched within the same calendar year. Therefore, there was a unique match for each cancer case. Since new cancer cases were observed on an annual basis, only the individuals from the same year from the Canadian Cancer Registry and income files were considered. For example, the cancer survivors from the year 1992 was matched with the control group from the same calendar year. This process was

repeated every year until 2008. Once the cancer survivors and the control group were matched, we obtained the impact of cancer diagnosis on labour market earnings using the difference-in-difference method.

The Mahalanobis' distance and propensity score matching was conducted by using PSMATCH2 program (Leuven and Sianesi 2003, 2018) in STATA 14 software. In order to ensure that the propensity score and the subsequent match were done correctly, we verified the results by estimating the propensity scores and executing the matching manually as an additional measure of quality control.

Difference-in-Difference Estimation

Once the cancer survivors and the control group were matched, we proceeded to estimate the impact of cancer diagnoses on annual labour market earnings by using the difference-in-difference (DiD) estimator. An advantage of the difference-in-difference method is that it eliminates the unobserved time-invariant characteristics that may influence the labour outcomes between the cancer survivors and the control group.

In our model, *t*=0 is the year of the cancer diagnosis. Calendar years before and after the year of a cancer diagnosis are represented as t$\pm$s, where s=-1,-2 represents pre-cancer diagnosis years, and s=0,…,5 represents post-cancer diagnosis years. The DiD estimator allows us to draw comparisons between cancer cases before cancer diagnosis t=-1,-2 and after t+s $\geq$ 0 with our matched control group. The following equations represent the difference-in-difference estimator approach used:

$$\gamma_{i,t-1,2,-1,t+s} = \beta_o + \beta_1 T_i + \beta_2 W_{t+s} + \beta_3 (W_i \, x \, T_{i,t+s}) + \varepsilon_{t+s} \quad (4)$$

By inspecting the above equation, the coefficients can be interpreted the following ways:

- $\gamma_{i,t+s}$ is our outcome variable, which is reported income in time, t-2 to t+5 (t=0 indicates the time of cancer diagnosis)
- T_i is a dummy variable taking the value of 1 for cancer, and 0 for the control group
- W_{t+s} is a dummy variable taking the value of 1 in post-cancer diagnosis year $t+s$ and 0 before cancer diagnosis
- β_1 represents cancer survivors specific effect (to account for the average difference between the cancer survivors and the control group)
- β_2 indicates time trend common to the cancer survivors and the control group
- β_3 represents the true effect of treatment. The term $W_i \; x \; T_{t+s}$ is an interaction term, and its coefficient represents the difference-in-difference estimator for the effects of cancer diagnoses on labour market earnings among cancer survivors

Table 3 summarizes the interpretation of the coefficients in equation (4).

[Insert Table 3. Difference-in-difference (DID) estimator]

Results

In the results section, we provide descriptive statistics on the cancer survivors and the control group after the application of the Mahalanobis' distance and propensity score matching, graphical results on the overall impact of cancer diagnosis on labour market earnings, followed by the difference-in-difference regression results. We described the results for the DiD model, to consider the impact of cancer diagnosis of all, 4, and 12 cancer types stratified by age-groups—those less

than 55 years old and the 55 and up age group[3]—and sex over the follow-up period. All the results are shown using 2016 Canadian dollars.

The matched sample

Table 4 shows the difference in the characteristics of the cancer survivors and the control group. The most notable difference was the average age between the control group and the cancer survivors. Cancer survivors were much older (49.7) compared to the control group (41.03). This may have to do with a positive relationship between the incidence of cancer and age. Also, the cancer survivors'' average labour market earnings were much less than that of the control group. For the cancer survivors, there were fewer numbers of both immigrants and visible minorities. Balanced covariates after the application of the Mahalanobis' distance and propensity score matching are shown on the right column of Table 4.

[Insert Table 4 here]

Graphical results

The graphical results serve two purposes. First, they provide a visual description of the changes in average annual labour market earnings for the cancer survivors and the control group over time. Secondly, they allow us to test the common trend assumption that is necessary for the difference-in-difference (DID) regression.

[Insert figure 3 here]

[3] For ease of description and to keep the terminology consistent with the existing literature, those less than 55 years old will be referred to as the active group, whereas the 55 and up age group will be referred to as the less-active group

Figures 3 and 4 show a change in annual labour market earnings plotted over time (t=-2 to t=5). Both show clear evidence for a decrease in average annual labour market earnings for all male and female cancer survivors. Dissecting Figure 3 a bit further, we found a "U-shaped" trajectory of labour market earnings for male cancer survivors and a different pattern of recovery across age groups over the follow-up period. The cancer survivors in the age group 45–54 showed the largest labour market earnings loss compared to the control group, and this might be explained by the fact that this age group represents the most active age group in the labour force. To assess the common trend assumption, we examined annual labour market earnings across the cancer survivors and the control group before the cancer diagnosis. The average annual labour market earnings in the 2 years prior to the diagnosis were similar, showing a closely aligned trend and no particular change in earnings among the treated. Therefore, we can conclude that both cancer survivors and the control group earned similar labour market earnings and can rule out any presence of exogenous effect on the cancer survivors.

[Insert figure 4 here]

Figure 4 shows the change in labour market earnings for female cancer survivors by age groups. Here we can verify the common trend assumption, as the 2 years of previous labour market earnings followed the same trend between the cancer survivors and the control group. Overall, the female cancer survivors followed a similar trend: there was a loss in the annual labour market earnings at the time of cancer diagnosis, which reached its peak a year following the diagnosis, and then the annual labour market earnings showed a sign of recovery at t=2 and continued to close the difference in earnings between the cancer and the control group. In fact, younger cohorts with cancer recovered their labour market earnings at a faster rate, and the difference in earnings between the cancer survivors and the control group was almost non-existent at t=5, 5 years

following the cancer diagnosis. Other aspect of Figure 4 follows a similar trend, showing that the cancer diagnosis had a negative impact on annual labour market earnings, and the impact was at its greatest at t=1. Age group 45–54 receives particular attention, as this group of individuals represents the most active labour market group. The annual labour market earnings difference reached its maximum amount where the cancer survivors earned about $12,000 less compared to the control group at t=1. The annual labour market earnings of the cancer survivors rebounded at t=4 but the cancer survivors still earned approximately $7,000 less. This particular age group showed a persistent difference, and the cancer survivors never fully recovered the income loss even at t=5.

[Insert figure 4 here]

Difference-in-difference (DiD) regression results

In this section, the following sets of results are presented for the change in annual labour market earnings using the difference-in-difference regression. The results are stratified by age-groups—less than 55 years old and greater than or equal to 55 years old—and sex over a course of the 5-year follow-up period for all cancer types (Table 5); 4 major cancer types (Tables 6,7, and 8); 12 cancer types (Tables 9 and 10).

All cancer types

The DiD regression results using a specification (Equation 5) are presented in this section of the paper. In Table 5.1, we show the impact of cancer diagnosis over time stratified by age group and sex. All the reported changes in annual labour market earnings were compared to the baseline income, set at t=-1, 1 year before the cancer diagnosis. Considering the labour market earnings for all sexes with cancer, we observed the "U-shaped" curve trajectory of a labour market earnings

over a 5-year follow-up period. For example, cancer survivors in the active group, including both males and females, earned $11,244 (2016 CAD) less compared to the control group at *t*=1, or 1 year after the cancer diagnosis. Starting at *t*=2, or 2 years after the diagnosis, we observed a rebound in the labour market earnings and at *t*=5, or 5 years after the diagnosis, the cancer survivors earned $6,891 less compared to the control group. Individuals in the less-active group for all sexes, earned approximately $10,687 less compared to the control group at *t*=1 but the rate of recovery in labour market earnings was much slower compared to that of the less than 55 years old group. Comparing the labour market earnings between males and females, we observed that the male cancer survivors suffered relatively higher losses in labour market earnings compared to their female counterparts but observed similar "U-shaped" trajectories for both males and females.

[Insert table 5.1 here]

Table 5.2 shows the percent (%) change in annual labour market earnings between the cancer survivors and the control group. Here, we also observed the "U-shaped" trajectory of labour market earnings change. The impact of a cancer diagnosis was more persistent in the first 3 years after the diagnosis for the less-active age group. Considering the change (%) in labour market earnings across the sexes, males in the less-active group earned 22.73% less at *t*=3 compared to their counterparts, whereas the females in the less-active group earned 24.16% less at *t*=3.

[Insert table 5.2 here]

Four major cancer types

In the previous section, we looked at the impact of all cancer diagnoses on annual labour market earnings and thus did not make a distinction between different cancer types.

[Insert table 6 here]

The combined impact of 4 cancer types on annual labour market earnings is shown in Table 6. Considering the labour market earnings changes for the cancer survivors across two age groups, we observed that the active group (less than 55 years old) earned $12,207.6 (31.41%) less, whereas the less-active group (55 and up) earned $9,819.8 (29.25%) less compared to the control group. Another key finding is that the impact of cancer diagnosis was more persistent for the less-active group, since this group still earned 16.36% less at t=5, compared to 13.66% of the active group.

[Insert table 7.1 here]

In Table 7.1, we reported nominal ($) changes in labour market earnings due to the 4 cancer types—breast, colorectal, lung and prostate—and investigate the heterogenous effects. Across all 4 cancer types, we observed "U-shaped" earnings trajectories, where the largest labour market earnings difference or the loss of earnings was reported at t=1, followed by a recovery of labour market earnings starting at t=2. Here, we observed two extreme impacts of cancer diagnosis on labour market earnings. On one hand, the smallest loss of labour market earnings was observed for the prostate cancer survivors for both the active and the less-active groups, where the prostate cancer survivors earned $6,046 and $11,324 less respectively at t=1 compared to the control group. On the other hand, the largest loss in labour market earnings was observed for the lung cancer survivors, where the lung cancer survivors earned $23,734 less for active group, and $14,807 less for the less-active group at t=1 compared to the control group. All the results were found to be statistically significant at a p-value less than 0.001.

[Insert table 7.2 here]

Table 7.2 shows the time-varying effects of 4 cancer types in terms of % in labour market earnings. The lung cancer survivors earned 53.81% less at t=1, which implies that their counterparts (the non-cancer population) earned 53% more earnings compared to the lung-cancer survivors. The breast cancer survivors earned 20.75% less at t=1 compared to the control group. Considering all 4 cancer types, lung cancer has the highest impact on labour market earnings, followed by colorectal, breast, and prostate cancers. This finding shows that labour market earnings loss is related to the severity of the cancer type, and that there is a heterogenous effect of cancer.

Twelve cancer types:

We will be presenting the remaining 8 cancer types in this section since the results of the 4 cancer types were shown in Table 7. As was shown in Table 7, cancer survivors earned less compared to the control group, and the magnitude of decrease in labour market earnings was closely aligned with the severity of the cancer type.

[Insert table 8.1 here]

[Insert table 8.2 here]

[Insert table 9.1 here]

[Insert table 9.2 here]

Considering the skin cancer survivors, the least severe type of cancer in terms of the 5-year survival rate, we observed the smallest change in labour market earnings; the active group earned $907.69 (2.74%) less, whereas the less-active group earned $607.6 (1.57%) less at t=1 compared to the control group. At t=5, or 5-years after the initial diagnosis, the active group earned $183.50

(0.38%) less, whereas the less-active group earned $293.1 (0.5%) more compared to the control group. Considering the most severe type of cancer, which is pancreatic cancer, this cancer survivors earned $28,805 less for the active group, and $39,490 for the less-active group at t=1 compared to the control group. For this cohort, labour market earnings began to recover starting at t=2 but the most severe cancer types still had a persistent difference in labour market earnings even at t=5. A graphical representation of a change in labour market earnings across 12 different cancer types is shown in Figure 5.

Discussion

In this study we identified a negative effect of cancer on labour market earnings, which are statistically significant and consistent with previous research (Bradley et al., 2002, 2005, 2007; Jeon 2017; Moran et al., 2011). More importantly, we identified that the loss of labour market earnings over time followed a "U-shaped" trajectory, where the lowest point or the largest labour market earnings loss occurred at t=1 or 1 year after the cancer diagnosis. There may be several reasons for labour market earnings losses, including a change in an individual's preference for working after diagnosis, as well as the need for time off work for ongoing cancer treatments including long-term adjuvant chemotherapy, or residual physical problems from successive treatments such as radiation damage. For example, individuals who are diagnosed with cancer may choose to withdraw from the labour force or make modifications to their job to make it less demanding as a result of a cancer diagnosis. There seems to be a growing consensus that active cancer treatment may explain part of the "U-shaped" curve. According to the National Cancer Institute (2018), most individuals with cancer go through a total of 3 cycles of treatments, where 1 cycle can range from 2 to 6 weeks (or up to 18 months after the completion of 3 cycles). It is during this intensive treatment period where individuals may withdraw from the labour force

(Hopkins et al., 2010; Lauzier et al., 2012) or reduce working hours (Moran et al., 2011). Unfortunately, without having access to labour market level information, it is not clear which of the two factors comes first and exerts a greater influence on the income loss among cancer survivors.

The reported labour market earnings loss is substantial, considering that average out-of-pocket costs associated with cancer treatment are about $2,900 per year (Longo et al., 2006) and about $26,000 for healthcare-related costs (de Oliveria et al., 2013). Another Canadian-based study by Hopkins, Goeree, and Longo (2010) has found an average income loss of $7,404 using direct survey, and $4,978 using national survey data, which further supports our results. The difference in results may have to do with the short-term follow-up nature of the study mentioned above, where it failed to capture the loss of income beyond 1 year after the cancer diagnosis. Given the median individual income in Canada was $34,000 in 2015 (Cansim table 206-0052), the economic burden of cancer in the first year after the diagnosis amounts to $11,000 or 32% of the labour market earnings approximately.

Cancer survivors' labour market earnings showed a sign of recovery at 2 years after initial diagnosis. Following diagnosis, labour market earnings recovery increased, and the magnitude of earnings losses compared to the control group became progressively smaller in the years following initial cancer diagnoses. One year after diagnosis, cancer survivors earned $11,244 less compared to the control group in the active age group. Two and three years after the diagnosis, the active age group showed a difference of $8,596 and $7,124 respectively. This result is consistent with Jeon and Pohl (2017), where the authors have found that cancer survivors suffered a loss of $4,832 at T+1, $3,825 at T+2, and $3,629 at T+3. The "U-shaped" curve can be partially explained by cancer survivors' higher rate of return to work (Jeon and Pohl, 2016) as the authors have found that cancer

survivors had a rebound in their income as more cancer survivors returned to work. For example, in the first year after the diagnosis, cancer survivors were 3.0 % less likely to work compared to the control group. However, in the third year, they were only 1.4 % less likely to work. The authors' estimated effects are smaller than those in this study, which may be explained by a different sample selection, our longer follow-up period, and our inclusion of more cancer types.

We found heterogeneous effects of cancer types on labour market earnings, following the severity of cancer. The labour market earnings loss was the largest for pancreatic cancer survivors, where the pancreatic cancer survivors earned $28,805 less compared to the control group at t=1 for active-age group. Considering the least severe type of cancer, we found that skin cancer survivors earned $607 less at t=1 but earned $293 more at t=5 for the less-active age group, meaning that skin cancer survivors earned higher earnings than their non-cancer counterparts. The same pattern was observed for the less-active breast cancer survivors, which showed that breast cancer survivors earned $970 (5%) more at t=5. The relationship between the magnitude of labour market earnings loss and the severity of cancer is less well-understood, but a study by Syse et al. (2008) found results that corroborate our findings. Specifically, the authors have found that individuals with lung and brain cancer showed 49.3% and 45.4% lower labour market earnings compared to individuals without cancer. Skin cancer survivors experienced a minor difference in income relative to their peers: 5% or $2,000 increase in income for males, and 3.8% or $970 decrease in income for females following the diagnosis. Considering that both breast and skin cancer survivors had a higher overall survival rate compared to other types of cancer (Canadian Cancer Society, 2018**),** one can speculate that breast and skin cancer survivors in the less-active age group might be more motivated and thus willing to work more to make up for the loss of earnings as this group of individuals are closer to the retirement age of 65. It is also possible that

the more severe cancer types require more intense treatment, which may affect an individual's willingness and ability to work. There is some evidence to support this interpretation (Zajacova et al., 2015), but there is a need for future studies to provide more insight on the relationship between cancer type, follow-up treatments, and labour outcomes across different cancer types.

Labour market activity and subsequent changes in labour market earnings following diagnosis of cancer could also be associated with age at onset: the active and the less-active labour force groups. For example, given the lower labour market participation of older individuals (aged 55+) who are close to standard retirement age, a cancer diagnosis may push older individuals to exit the labour force sooner. In other words, the initial loss of labour market earnings is more pronounced for this group of individuals and the loss might be more persistent since many of them may live on fixed income post-retirement. Individuals who are in the active age group (25–54) might suffer a temporary setback in labour market earnings during active treatment and thus face higher losses but recover quickly as they return to work. This is what we found in our study.

Strengths of our study include the data and the analytic approach. The linked cancer dataset and income files give rise to a powerful longitudinal dataset with invaluable information on the income sources and amounts of Canadians, including individuals with cancer. The Mahalanobis' Distance and Propensity Score Matching combined with the difference-in-difference regression method is a unique research design which allowed us to identify the effect of cancer on the annual labour market earnings of individuals.

Overall, our study is consistent with the literature that considers the impact of cancer diagnosis on labour market earnings. It adds to the evidence on the heterogeneity of labour market earnings of individuals, by cancer type, following cancer diagnosis. On average, we find that the magnitude of labour market earnings loss is significant, both in magnitude and statistically,

suggesting that the strain may be also be significant for cancer survivors who are dealing with both the monetary and psychosocial costs of cancer. While not the aim of this study, the results provide further evidence to support the idea of policy interventions to alleviate the financial burden of cancer survivors by extending the employment insurance coverage beyond the 15 weeks that is publicly provided in Canada (Government of Canada, 2019), as well as return to work policy that could assist cancer survivors to transition back to work place.

In terms of research limitations, our study calls for more rigorous data collection on cancer-related information. Despite our best efforts to use the Mahalanobis' Distance and Propensity Score Matching combined with the difference-in-difference method to disaggregate the effect of different cancer types on annual labour market earnings, we did not have data on the severity of the disease (e.g., stages of cancer) within cancer type. This lack of observation may prevent us from identifying the combined effect of severity of cancer and the age of onset on the labour market outcomes among cancer survivors, where terminal stage (Stage 4) breast cancer survivors in the less active age group may leave the labour force and live on a fixed income, compared to stage 0 breast cancer survivors who would remain in the labour force during the treatment and suffer a less labour market earnings loss. Hence, our results should be interpreted as the average effect of different cancer types on annual labour market earnings. To address this issue, governments could encourage health care providers to record cancer staging information at the time of diagnosis since only about 10% of the cancer records contained staging information in our data. Such initiatives to record cancer staging information would provide a richer dataset, and thus enable researchers to use the cancer staging information to conduct more in-depth analyses.

As the objective of this study was to estimate the change in labour market earnings among cancer survivors over the follow-up period of 5 years since the diagnosis, the study does not

include those who may have died and had recurrence of cancer, approximately 23% of our total sample. The results of the cancer should be interpreted with caution as the permanent loss of labour market earnings due to death, and any setbacks due to recurrence of cancer are not captured. Therefore, our results may underestimate the impact of cancer diagnosis on labour market earnings.

We found persistent losses of labour market earnings even at t=5, 5 years after the initial diagnosis for most cancer types except cancer survivors with breast, cervix and skin cancer in the less-active age group, which suggests that a longer follow-up might be considered in future studies to better understand the long-run impact of cancer diagnoses on labour market earnings.

There is another limitation inherent in our data that might affect our estimates. We used linked annual tax record files to capture the loss of labour market earnings due to a cancer diagnosis. However, this may not capture the real loss, as labour market earnings is only one source of income. We did not consider other income sources such as wage replacement from private and public disability insurance sources.

Conclusion

Our study substantiates existing evidence that cancer diagnoses negatively affect labour market earnings. It also demonstrates that labour market earnings losses can persist for up to 5 years after diagnosis. The magnitude of labour market earnings loss is found to be both statistically significant and economically substantial. Our primary contribution to the literature is the documentation of the heterogenous effects of cancer types on labour market earnings. Particularly noteworthy is that more severe types of cancer, in terms of the 5-year survival rate, are related to higher losses of labour market earnings. We found the pattern of labour market earnings loss over time has a "U-shape", with cancer survivors having labour marking earnings recovery 2 years after the initial diagnosis. This is consistent with other published literature. A policy implication of our result is that policy makers might consider providing support to individuals through employment insurance sickness benefits beyond the current 15-week maximum in order to mitigate longer run financial losses of individuals afflicted with cancer during their working lives.

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Table 1. The distribution of cancer types(sites)

Cancer types identified by ICD-10	Number of observations	Proportion of distribution (%)
Esophagus	1,844	3.1
Stomach	1,178	1.98
Colorectal	7,310	12.28
Liver	1,207	2.03
Pancreas	1,190	2
Nasal cavity and middle ear	48	0.08
Lung	8,275	13.9
Heart	320	0.54
Blood	2,577	4.33
Skin	2,280	3.83
Nerve system	441	0.74
Breast	8,667	14.56
Cervix	3,090	5.19
Prostate Glands	10,692	17.96
Male reproductive organ	292	0.49
Kidney	1,625	2.73
Renal pelvis	89	0.15
Female reproductive organ	54	0.09
Bladder	2,357	3.96
Unspecified urinary organs	113	0.19
Eye and Adnexa	137	0.23
Meninges	24	0.04
Brain	953	1.6
Spinal cord, cranial nerves, and others	24	0.04
Thyroid gland	1,208	2.03
Adrenal gland	30	0.05
Other endocrine glands and related site	18	0.03
other, and ill-defined sites	48	0.08
Lymph nodes	2,292	3.85
Unknown	1,149	1.93
Total number of observations	**59,532**	**100.00**

Table 2. Cancer diagnosis age distribution

Age at diagnosis	Number of observations	Proportion of distribution (%)	Cumulative distribution (%)
25 to 29	287	0.48	0.48
30 to 34	899	1.51	1.99
35 to 39	2,619	4.40	6.39
40 to 44	6,197	10.41	16.80
45 to 49	9,876	16.59	33.39
50 to 54	12,674	21.29	54.68
55 to 59	12,210	20.51	75.19
60 to 64	8,549	14.36	89.55
65 to 69	3,679	6.18	95.73
70 to 74	1,524	2.56	98.29
75 to 79	708	1.19	99.48
80 to 84	310	0.52	100.00
Total	**59,532**	**100.00**	**100.00**

Table 3. Difference-in-difference estimator

	Before cancer diagnosis	After cancer diagnosis	Difference
Cancer population	$\beta_0 + \beta_1$	$\beta_0 + \beta_1 + \beta_2 + \beta_3$	$\beta_2 + \beta_3$
Non-cancer population	β_0	$\beta_0 + \beta_2$	β_2
Difference	β_1	$\beta_1 + \beta_3$	β_3

Table 4: Descriptive statistics of treatment vs. control group after matching

Variable Description	Unmatched		Matched	Unmatched difference
	Treatment	Control	Control	
Individual's age	49.70	41.03	49.68	8.67***
Disability amount for self	$86.47	$43.36	$90.58	43.11**
Individual reported income	$37,937.44	$33,328.01	$37,396.34	-$5390.57***
Share of personal income to total family income	0.49	0.52	0.49	-0.03
Family size	2.14	2.49	2.13	-0.35**
Highest level of education				
No high school	0.23	0.21	0.23	0.019***
High school	0.38	0.42	0.38	-0.036***
Postsecondary non-university	0.21	0.19	0.21	0.015**
University degree	0.17	0.14	0.17	0.032***
Immigration status				
Immigrant	0.22	0.27	0.22	-0.05*
Sex				
Male	0.52	0.54	0.52	-0.02*
Visible minority status				
Minority	0.06	0.08	0.06	-0.02*
Self-employment				
Self-employed	0.07	0.14	0.08	-0.07**
Disability status				
Disabled	0.03	0.05	0.027	-0.02*
Marital status				
Divorced	0.07	0.08	0.08	-0.009*
Legally married	0.77	0.75	0.76	0.02*
Never married	0.11	0.08	0.12	0.03**
Other	0.05	0.09	0.04	-0.041
Sample size	59,532	243,446	143,941	

***** significantly different from control group ($p < 0.05$)
** significantly different from control group ($p < 0.01$)
*** significantly different from control group ($p < 0.001$)
Note: The last column represents the difference between control and treatment group before matching. The above symbols represent the significance of t-test. Pre-cancer (t=-1) characteristics were used for matching
Source: 1991 Canadian Census Health and Environment Cohort (CanCHEC)

Table 5.1. The effect of cancer diagnosis on annual labour market earnings ($) by age groups and sex

	Annual labour market earnings ($)					
	All sex		Male		Female	
	< 55	≥ 55	< 55	≥ 55	< 55	≥ 55
T=-1	Reference year					
T=0						
Coefficient	-6113.8***	-5232.6**	-7620.2	-5716.1*	-5192.3***	-4764.7***
Standard error	(1460.4)	(1870.7)	(4561.5)	(2727.4)	(668.94)	(949.18)
T=1						
Coefficient	-11244.0***	-10687.1***	-12842.4**	-12337.6***	-10124.9***	-7815.4***
Standard error	(1468.3)	(1895.1)	(4579.1)	(2768.3)	(672.52)	(958.21)
T=2						
Coefficient	-8596.1***	-10298.8***	-8898.4**	-12660.5***	-7528.0***	-6882.8***
Standard error	(1460.6)	(1916.0)	(4463.8)	(2806.3)	(673.53)	(964.24)
T=3						
Coefficient	-7124.1***	-9585.8***	-7743.7**	-11678.6***	-6891.4***	-7597.4***
Standard error	(1469.8)	(1925.0)	(4521.9)	(2824.5)	(676.13)	(965.60)
T=4						
Coefficient	-6827.5***	-7022.1**	-6841.9*	-6632.0*	-6818.3***	-7126.1***
Standard error	(1480.0)	(1937.2)	(4536.3)	(2843.1)	(681.61)	(971.61)
T=5						
Coefficient	-6591.8***	-6307.0***	-6647.4*	-6231.6**	-6258.3***	-6322.9***
Standard error	(1475.7)	(1951.3)	(4558.5)	(2869.1)	(677.85)	(974.25)
N	477498	453905	173585	287938	303913	165967

***** significantly different from control group ($p < 0.05$)
** significantly different from control group ($p < 0.01$)
*** significantly different from control group ($p < 0.001$)
Notes; The time period of cancer diagnosis is $t = 0$

- To estimate the age group-specific cancer effects, age categories are included
- All DiD regression include full set of control variables listed in methodology section
- < 55 refers to individuals aged less than 55 at the time of cancer diagnosis
- ≥ 55 refers to individuals aged greater than or equal to 55 at the time of cancer diagnosis

Source: 1991 Canadian Census Health and Environment Cohort (CanCHEC)

Table 5.2. Percent (%) change in annual labour market earnings by age groups and sex

	Annual labour market earnings (%)					
	All sex		Male		Female	
	< 55	≥ 55	< 55	≥ 55	< 55	≥ 55
T=-1	**Reference year**					
T=0						
Coefficient	-0.1493***	-0.1396***	-0.1724***	-0.1115***	-0.1373***	-0.1602***
Standard error	(0.02195)	(0.02005)	(0.04131)	(0.02388)	(0.02609)	(0.03705)
T=1						
Coefficient	-0.2776***	-0.2606***	-0.2525***	-0.2483***	-0.2857***	-0.2621***
Standard error	(0.02214)	(0.02092)	(0.04172)	(0.02495)	(0.02628)	(0.03852)
T=2						
Coefficient	-0.1928***	-0.2343***	-0.2011***	-0.2456***	-0.1884***	-0.2226***
Standard error	(0.02204)	(0.02156)	(0.04074)	(0.02581)	(0.02635)	(0.03942)
T=3						
Coefficient	-0.1724***	-0.2330***	-0.1744***	-0.2273***	-0.1704***	-0.2416***
Standard error	(0.02232)	(0.02228)	(0.04139)	(0.02666)	(0.02665)	(0.04079)
T=4						
Coefficient	-0.1636***	-0.1766***	-0.1616***	-0.1258***	-0.1684***	-0.2217***
Standard error	(0.02251)	(0.02327)	(0.04166)	(0.02789)	(0.02690)	(0.04244)
T=5						
Coefficient	-0.1512***	-0.1703***	-0.1605***	-0.1143***	-0.1441***	-0.1913***
Standard error	(0.02258)	(0.02427)	(0.04204)	(0.02917)	(0.02692)	(0.04401)
N	477498	453905	173585	287938	303913	165967

***** significantly different from control group ($p < 0.05$)
** significantly different from control group ($p < 0.01$)
*** significantly different from control group ($p < 0.001$)
Notes; The time period of cancer diagnosis is $t = 0$

- < 55 refers to individuals aged less than 55 at the time of cancer diagnosis
- ≥ 55 refers to individuals aged greater than or equal to 55 at the time of cancer diagnosis

Source: 1991 Canadian Census Health and Environment Cohort (CanCHEC)

Table 6. The effect of 4 major cancer diagnosis on annual labour market earnings ($ and %) by age groups

	Annual labour market earnings ($)			
	$ change		% change	
	< 55	≥ 55	< 55	≥ 55
T=-1	**Reference year**			
T=0				
Coefficient	-6416.9***	-4008.8*	-0.1577***	-0.1418***
Standard error	(1660.8)	(1856.6)	(0.02284)	(0.02079)
T=1				
Coefficient	-12207.6***	-9819.8***	-0.3141***	-0.2925***
Standard error	(1672.6)	(1884.3)	(0.02312)	(0.02177)
T=2				
Coefficient	-7535.4***	-8996.2***	-0.1980***	-0.2686***
Standard error	(1668.5)	(1908.4)	(0.02309)	(0.02251)
T=3				
Coefficient	-6572.4***	-8983.6***	-0.1632***	-0.2615***
Standard error	(1680.7)	(1919.4)	(0.02341)	(0.02332)
T=4				
Coefficient	-6350.2***	-5395.0**	-0.1583***	-0.1778***
Standard error	(1693.9)	(1931.9)	(0.02365)	(0.02439)
T=5				
Coefficient	-5118.1***	-4919.3***	-0.1366***	-0.1636***
Standard error	(1691.2)	(1946.5)	(0.02376)	(0.02547)
N	200435	194712	200435	194712

***** significantly different from control group ($p < 0.05$)
** significantly different from control group ($p < 0.01$)
*** significantly different from control group ($p < 0.001$)
Notes; The time period of cancer diagnosis is $t = 0$

- < 55 refers to individuals aged less than 55 at the time of cancer diagnosis
- ≥ 55 refers to individuals aged greater than or equal to 55 at the time of cancer diagnosis

Source: 1991 Canadian Census Health and Environment Cohort (CanCHEC)

Table 7.1. The time-varying effect of 4 cancer types on annual labour market earnings ($) by age groups

	Annual labour market earnings							
	Breast		Prostate		Lung		Colorectal	
	< 55	≥ 55	< 55	≥ 55	< 55	≥ 55	< 55	≥ 55
T=-1	Reference year							
T=0								
Coefficient	-5074.2***	-2895.4***	-2237.8***	-2595.3**	-11083.7***	-6362.7***	-8464.0***	-4790.5***
Standard error	(727.50)	(2606.2)	(4441.3)	(2746.1)	(1483.1)	(2660.6)	(1326.6)	(2792.4)
T=1								
Coefficient	-9002.1***	-6812.2**	-6046.4***	-11324.6***	-23734.3***	-14809.5***	-15014.8***	-10375.8***
Standard error	(730.18)	(2626.0)	(4464.9)	(2775.4)	(1608.9)	(3004.3)	(1348.4)	(2867.9)
T=2								
Coefficient	-5988.4***	-5131.0***	-3956.7***	-11894.5***	-21692.2***	-12705.6***	-13243.9***	-9599.5***
Standard error	(726.81)	(2641.7)	(2455.9)	(2785.7)	(1842.3)	(3662.7)	(1372.8)	(2963.1)
T=3								
Coefficient	-4253.5***	-3150.8***	-1502.3***	-9527.9**	-18090.1***	-9447.6***	-11002.9***	-8643.9**
Standard error	(731.29)	(1661.4)	(1077.7)	(2799.4)	(2017.2)	(4129.9)	(1400.4)	(3046.5)
T=4								
Coefficient	-4041.6***	2053.8***	-1723.7***	-8645.5**	-16009.0***	-4402.7***	-11603.5***	-4618.5***
Standard error	(736.64)	(673.1)	(501.3)	(2817.7)	(2124.4)	(2375.9)	(1424.5)	(3107.2)
T=5								
Coefficient	-3870.3***	973.00***	-729.8***	-7567.0**	-15226.1***	-4050.4***	-11991.4***	-4494.5***
Standard error	(735.92)	(292.6)	(455.0)	(2761)	(2172.5)	(2556.8)	(1437.2)	(3150.3)
N	44250	24165	31176	51714	66372	63093	58637	55740

***** significantly different from control group ($p < 0.05$)
** significantly different from control group ($p < 0.01$)
*** significantly different from control group ($p < 0.001$)
Notes; The time period of cancer diagnosis is $t = 0$

- < 55 refers to individuals aged less than 55 at the time of cancer diagnosis
- ≥ 55 refers to individuals aged greater than or equal to 55 at the time of cancer diagnosis

Source: 1991 Canadian Census Health and Environment Cohort (CanCHEC)

Table 7.2. The time-varying effect of 4 cancer types on change (%) in annual labour market earnings by age groups

	% change in annual labour market earnings							
	Breast		Prostate		Lung		Colorectal	
	< 55	≥ 55	< 55	≥ 55	< 55	≥ 55	< 55	≥ 55
T=-1	**Reference year**							
T=0								
Coefficient	-0.1378***	-0.0878***	-0.0639***	-0.0643**	-0.2650***	-0.1954***	-0.2093***	-0.1329***
Standard error	(0.02333)	(0.02696)	(0.02739)	(0.02304)	(0.02752)	(0.02773)	(0.02714)	(0.02773)
T=1								
Coefficient	-0.2075***	-0.2137**	-0.1521***	-0.2206***	-0.5381***	-0.4206***	-0.3672***	-0.2806***
Standard error	(0.02356)	(0.02841)	(0.02773)	(0.02472)	(0.03197)	(0.03529)	(0.02803)	(0.03010)
T=2								
Coefficient	-0.1585***	-0.1773***	-0.1059***	-0.2288***	-0.5168***	-0.4073***	-0.3301***	-0.2757***
Standard error	(0.02349)	(0.02947)	(0.02781)	(0.0256)	(0.03709)	(0.04465)	(0.02881)	(0.03211)
T=3								
Coefficient	-0.1285***	-0.1177***	-0.0526***	-0.1998**	-0.4515***	-0.3498***	-0.2736***	-0.2549**
Standard error	(0.02380)	(0.03080)	(0.02810)	(0.02675)	(0.04044)	(0.05121)	(0.02953)	(0.03442)
T=4								
Coefficient	-0.1285***	0.1177***	-0.0685***	-0.1791**	-0.4237***	-0.1574***	-0.2896***	-0.1584***
Standard error	(0.02380)	(0.03080)	(0.02848)	(0.02793)	(0.04305)	(0.05660)	(0.03022)	(0.03665)
T=5								
Coefficient	-0.1196***	0.0497***	-0.0037***	-0.1689**	-0.3988***	-0.1496***	-0.2782***	-0.1451***
Standard error	(0.02417)	(0.03414)	(0.02882)	(0.02394)	(0.04305)	(0.06149)	(0.03065)	(0.03867)
N	44250	24165	31176	51714	66372	63093	58637	55740

***** significantly different from control group ($p < 0.05$)
** significantly different from control group ($p < 0.01$)
*** significantly different from control group ($p < 0.001$)
Notes; The time period of cancer diagnosis is $t = 0$

- < 55 refers to individuals aged less than 55 at the time of cancer diagnosis
- ≥ 55 refers to individuals aged greater than or equal to 55 at the time of cancer diagnosis

Source: 1991 Canadian Census Health and Environment Cohort (CanCHEC)

Table 8.1. The time-varying effect of 12 cancer types on annual labour market earnings ($) by age groups

	Annual labour market earnings							
	Blood		Cervix		Kidney		Bladder	
	< 55	≥ 55	< 55	≥ 55	< 55	≥ 55	< 55	≥ 55
T=-1	Reference year							
T=0								
Coefficient	-10882.5***	-8600.3***	-3573.2***	-1654.0***	-6716.3***	-4510.7***	-3879.9**	-3337.6**
Standard error	(1818.7)	(4426.1)	(1174.2)	(904.6)	(1682.5)	(5624.4)	(2004.0)	(2395.9)
T=1								
Coefficient	-20296.4***	-17061.3***	-4834.5***	-3223.3***	-7140.2***	-9770.0**	-3711.3**	-8182.9***
Standard error	(1864.7)	(4713.1)	(1184.8)	(985.5)	(1727.4)	(5944.5)	(2025.2)	(4601.8)
T=2								
Coefficient	-16696.9***	-16596.4***	-4623.2***	-1341.1***	-6073.9***	-10649.8**	-4737.3***	-6967.2**
Standard error	(1926.3)	(5015.4)	(1196.0)	(555.7)	(1761.9)	(6256.0)	(2043.2)	(4488.4)
T=3								
Coefficient	-14635.2***	-15966.1***	-2590.1***	438.88***	-6268.9***	-10166.6**	-3030.0***	-6599.6**
Standard error	(1978.8)	(5238.9)	(1207.0)	(217.5)	(1794.3)	(6412.1)	(2082.8)	(4680.7)
T=4								
Coefficient	-12488.0***	-10790.5***	-2172.7***	689.2***	-6683.5***	-9225.2**	-4055.6***	-3905.8*
Standard error	(2010.1)	(5383.0)	(1217.1)	(237.0)	(1805.9)	(6579.7)	(2085.6)	(2740.7)
T=5								
Coefficient	-10010.9***	-9324.4***	-2096.0***	443.3***	-5926.5***	-8032.9*	-3491.3***	-3771.9***
Standard error	(2032.0)	(5529.9)	(1222.1)	(161.1)	(1813.4)	(6622.6)	(2090.8)	(1757.1)
N	20676	19654	19768	18792	13036	12392	18909	17975

***** significantly different from control group ($p < 0.05$)
** significantly different from control group ($p < 0.01$)
*** significantly different from control group ($p < 0.001$)
Notes; The time period of cancer diagnosis is $t = 0$

- < 55 refers to individuals aged less than 55 at the time of cancer diagnosis
- ≥ 55 refers to individuals aged greater than or equal to 55 at the time of cancer diagnosis

Source: 1991 Canadian Census Health and Environment Cohort (CanCHEC)

Table 8.2. The time-varying effect of 12 cancer types on change (%) in annual labour market earnings by age groups

	% change in annual labour market earnings							
	Blood		Cervix		Kidney		Bladder	
	< 55	≥ 55	< 55	≥ 55	< 55	≥ 55	< 55	≥ 55
T=-1	Reference year							
T=0								
Coefficient	-0.2207***	-0.2072***	-0.0989***	-0.0466***	-0.1635***	-0.1148***	-0.0938***	-0.1107***
Standard error	(0.0338)	(0.0395)	(0.0272)	(0.0221)	(0.03259)	(0.04762)	(0.03575)	(0.03854)
T=1								
Coefficient	-0.4174***	-0.4143***	-0.1183***	-0.0923***	-0.1783***	-0.2391***	-0.0906***	-0.2548***
Standard error	(0.0362)	(0.0455)	(0.0278)	(0.0446)	(0.03406)	(0.05304)	(0.03653)	(0.04389)
T=2								
Coefficient	-0.3625***	-0.3871***	-0.1030***	-0.03513***	-0.1412***	-0.2413***	-0.1186***	-0.2380***
Standard error	(0.0378)	(0.0508)	(0.0282)	(0.0165)	(0.03485)	(0.05689)	(0.03717)	(0.04122)
T=3								
Coefficient	-0.2629***	-0.3573***	-0.0786***	0.0088***	-0.1467***	-0.2390***	-0.0743***	-0.2323***
Standard error	(0.0391)	(0.0546)	(0.0286)	(0.0048)	(0.03571)	(0.06063)	(0.03780)	(0.04646)
T=4								
Coefficient	-0.2234***	-0.2521***	-0.0752***	0.0042**	-0.1584***	-0.2230***	-0.0984***	-0.1335***
Standard error	(0.0401)	(0.0587)	(0.0291)	(0.0025)	(0.03609)	(0.06520)	(0.03829)	(0.04927)
T=5								
Coefficient	-0.2151***	-0.2129***	-0.0728***	0.0031**	-0.1428***	-0.2014***	-0.0832***	-0.1315***
Standard error	(0.0408)	(0.0620)	(0.0294)	(0.0017)	(0.03650)	(0.06971)	(0.03865)	(0.05230)
N	20676	19654	19768	18792	13036	12392	18909	17975

***** significantly different from control group ($p < 0.05$)
** significantly different from control group ($p < 0.01$)
*** significantly different from control group ($p < 0.001$)
Notes; The time period of cancer diagnosis is $t = 0$

- < 55 refers to individuals aged less than 55 at the time of cancer diagnosis
- ≥ 55 refers to individuals aged greater than or equal to 55 at the time of cancer diagnosis

Source: 1991 Canadian Census Health and Environment Cohort (CanCHEC)

Table 9.1. The time-varying effect of 12 cancer types on annual labour market earnings ($) by age groups

	Annual labour market earnings							
	Skin		Esophagus		Pancreas		Thyroid	
	< 55	≥ 55	< 55	≥ 55	< 55	≥ 55	< 55	≥ 55
T=-1	Reference year							
T=0								
Coefficient	-1527.3*	-1403.3**	-12088.1***	-19953.2***	-12193.3***	-14099.0*	-2469.0***	-3891.7***
Standard error	(498.4)	(314.3)	(1903.6)	(7237.1)	(2373.9)	(5899.9)	(1516.1)	(794.0)
T=1								
Coefficient	-907.69*	-607.6**	-25182.7***	-30830.3***	-28805.6***	-39490.3*	-2966.1**	-1191.4***
Standard error	(507.0)	(265.7)	(2116.2)	(8314.4)	(2862.9)	(16835.9)	(1522.9)	(808.9)
T=2								
Coefficient	-426.67***	-501.3***	-22757.8***	-26253.6*	-22757.8***	-34773.8*	-336.41**	-3132.8*
Standard error	(512.7)	(192.6)	(4042.6)	(12434.0)	(4042.6)	(17904.6)	(151.3)	(812.1)
T=3								
Coefficient	-839.44***	-481.0***	-20203.0***	-22122.0**	-14372.9***	-26253.6*	-413.47***	-3138.1*
Standard error	(324.3)	(121.1)	(2761.5)	(15218.3)	(4840.3)	(12434)	(157.1)	(813.8)
T=4								
Coefficient	-282.0***	-395.19**	-17100.2***	-12261.4*	-11658.2**	-24910.4**	-580.06*	-2466.0**
Standard error	(152.1)	(117.7)	(2873.3)	(8943.0)	(5064.2)	(7695.6)	(129.7)	(821.2)
T=5								
Coefficient	-183.5*	293.1***	-15757.7***	-11294.9*	-10506.5***	-22728.3	-839.53	-2095.6*
Standard error	(130.6)	(180.5)	(2946.0)	(8502.3)	(5490.8)	(18683.4)	(127.5)	(827.5)
N	18288	17385	14802	14071	9550	9078	9693	9214

***** significantly different from control group ($p < 0.05$)
** significantly different from control group ($p < 0.01$)
*** significantly different from control group ($p < 0.001$)
Notes; The time period of cancer diagnosis is $t = 0$

- < 55 refers to individuals aged less than 55 at the time of cancer diagnosis
- ≥ 55 refers to individuals aged greater than or equal to 55 at the time of cancer diagnosis

Source: 1991 Canadian Census Health and Environment Cohort (CanCHEC)

Table 9.2. The time-varying effect of 12 cancer types on annual labour market earnings (%) by age groups

	% change in annual labour market earnings							
	Skin		Esophagus		Pancreas		Thyroid	
	< 55	≥ 55	< 55	≥ 55	< 55	≥ 55	< 55	≥ 55
T=-1	**Reference year**							
T=0								
Coefficient	-0.03520*	-0.0397**	-0.2745***	-0.256***	-0.2673***	-0.2895*	-0.0558***	-0.091***
Standard error	(0.0245)	(0.04296)	(0.03883)	(0.04567)	(0.04428)	(0.05334)	(0.0271)	(0.0636)
T=1								
Coefficient	-0.02740*	-0.0157**	-0.5304***	-0.4044***	-0.5724***	-0.7181*	-0.0571***	-0.029***
Standard error	(0.0247)	(0.0074)	(0.04627)	(0.06161)	(0.06015)	(0.1773)	(0.0273)	(0.0067)
T=2								
Coefficient	-0.01818***	-0.0132**	-0.4783***	-0.3518***	-0.4448***	-0.633*	-0.0083***	-0.082*
Standard error	(0.0119)	(0.0047)	(0.05462)	(0.08210)	(0.08327)	(0.2043)	(0.0273)	(0.0504)
T=3								
Coefficient	-0.01881***	-0.012***	-0.4624***	-0.3389***	-0.2943***	-0.5145**	-0.0096***	-0.083
Standard error	(0.0052)	(0.0052)	(0.06057)	(0.09565)	(0.09983)	(0.1391)	(0.0027)	(0.0728)
T=4								
Coefficient	-0.0063***	-0.0099**	-0.3504***	-0.1719***	-0.2384***	-0.4959**	-0.013*	-0.0712**
Standard error	(0.0057)	(0.0045)	(0.06354)	(0.1090)	(0.1033)	(0.08087)	(0.0087)	(0.0367)
T=5								
Coefficient	-0.0038*	0.005***	-0.3347***	-0.1615***	-0.2094***	-0.4486	-0.019*	-0.0658*
Standard error	(0.0025)	(0.0056)	(0.06533)	(0.1193)	(0.1139)	(0.2014)	(0.0079)	(0.0396)
N	18288	17385	14802	14071	9550	9078	9693	9214

***** significantly different from control group ($p < 0.05$)
** significantly different from control group ($p < 0.01$)
*** significantly different from control group ($p < 0.001$)
Notes; The time period of cancer diagnosis is $t = 0$

- < 55 refers to individuals aged less than 55 at the time of cancer diagnosis
- ≥ 55 refers to individuals aged greater than or equal to 55 at the time of cancer diagnosis

Source: 1991 Canadian Census Health and Environment Cohort (CanCHEC)

Figure 1. Dataset linkage

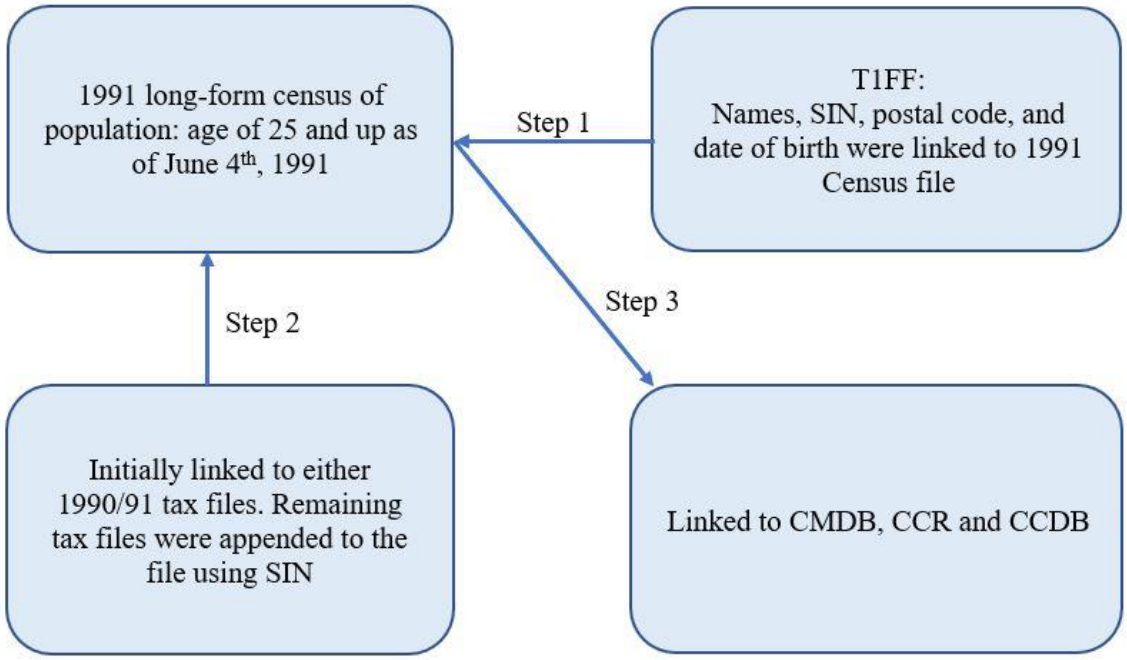


Figure 2. Sample selection process

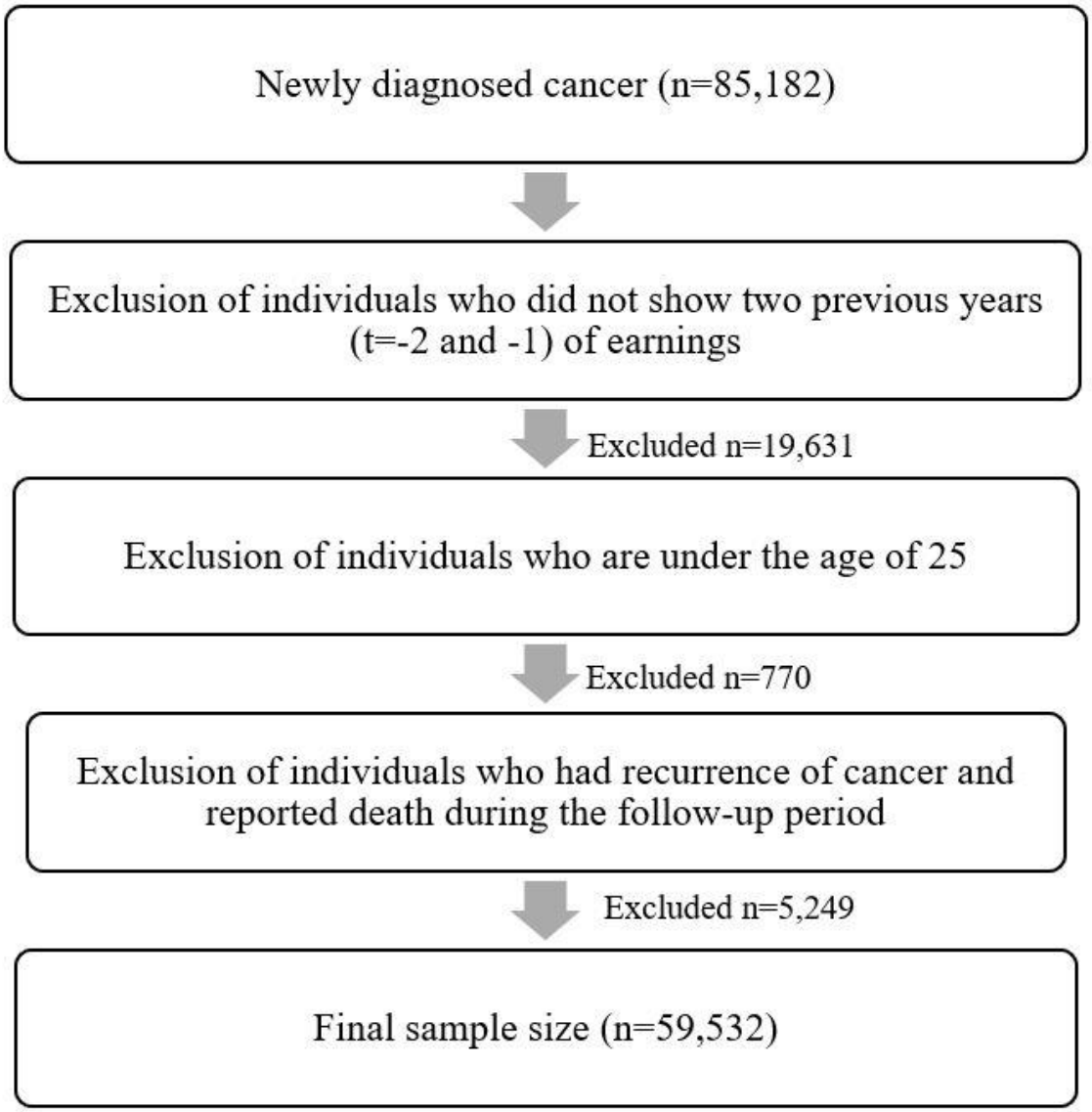


Figure 3. Change in annual labour market earnings ($) for males by age groups

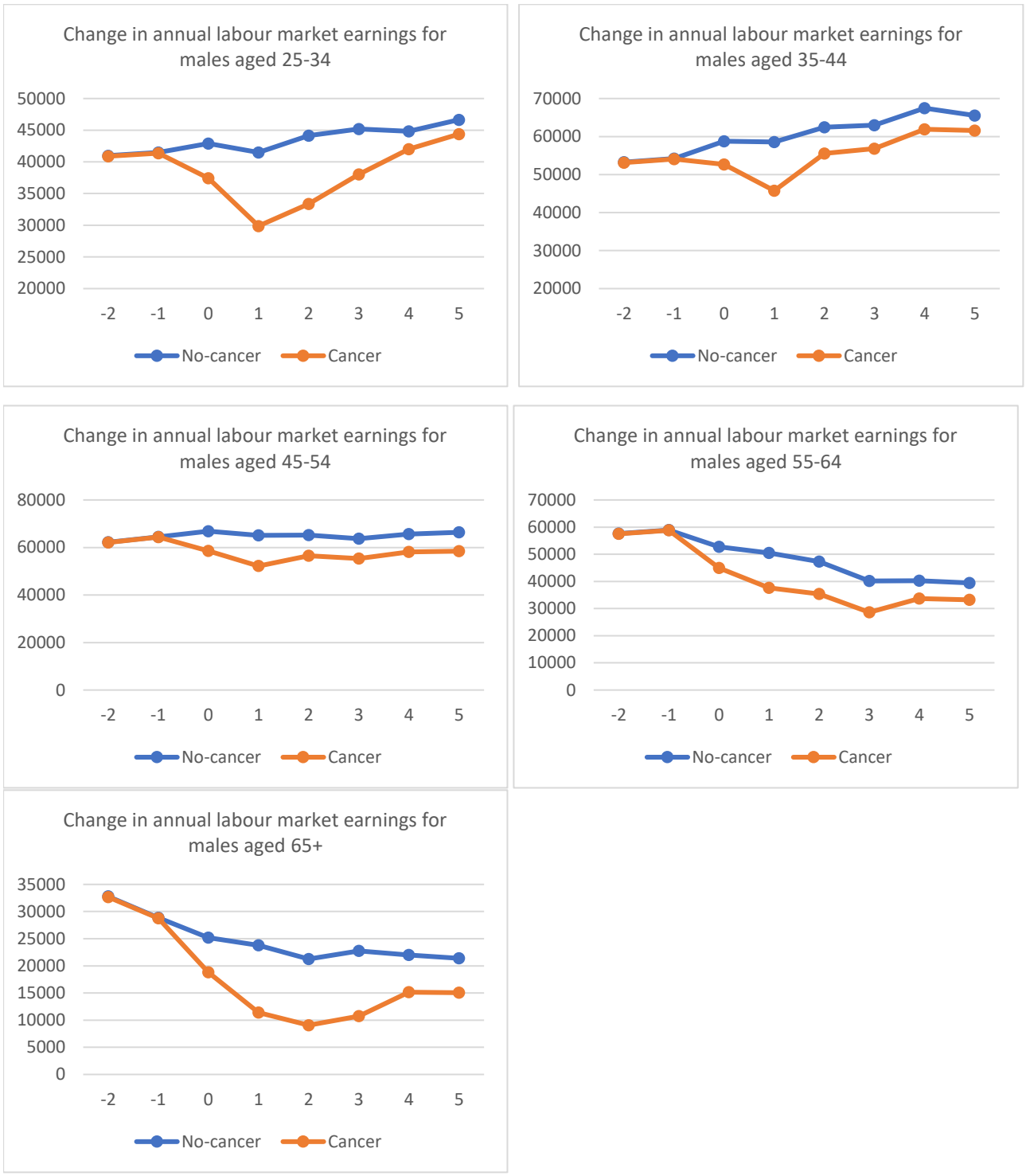


Figure 4. Change in annual labour market earnings ($) for females by age groups

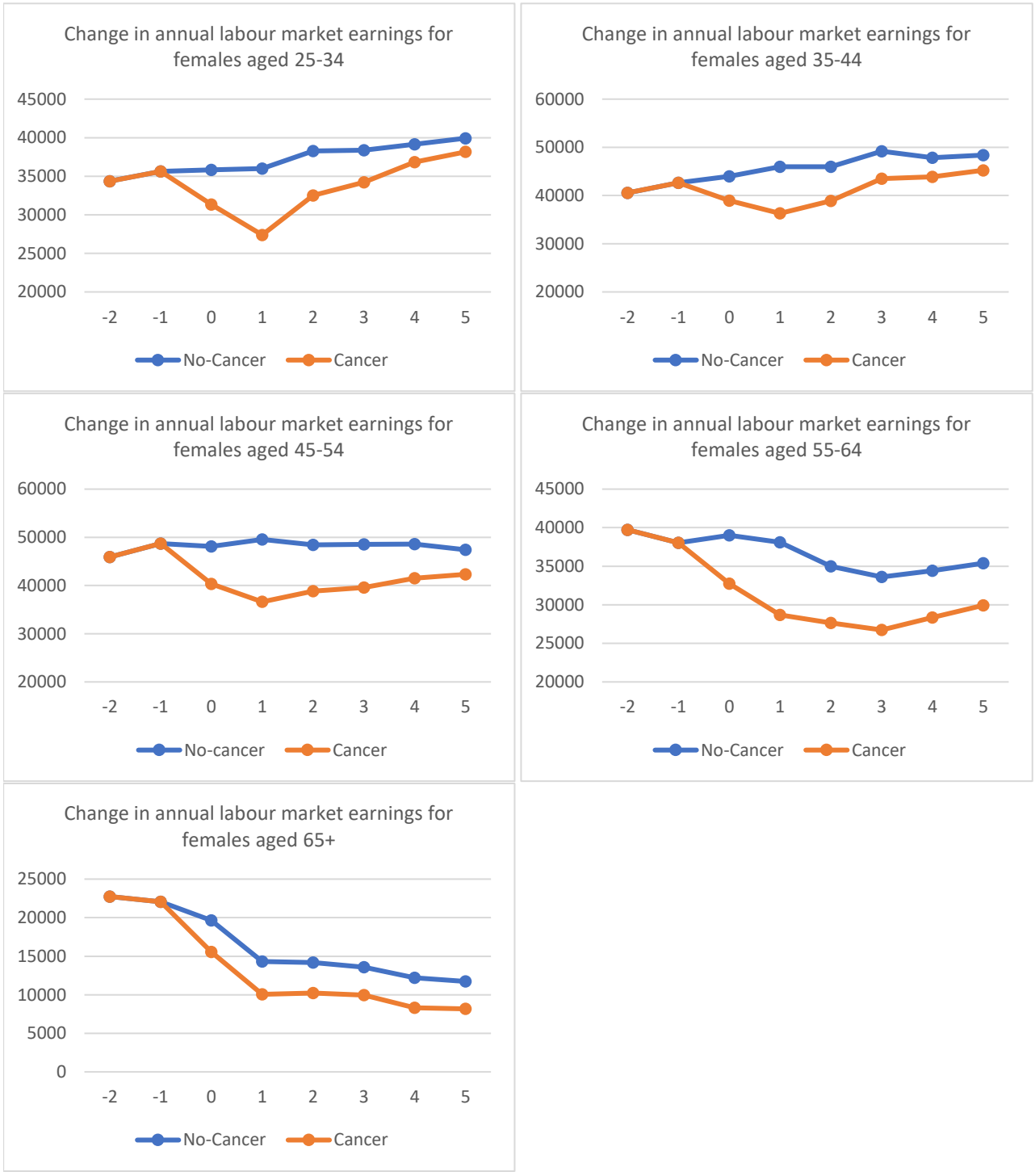
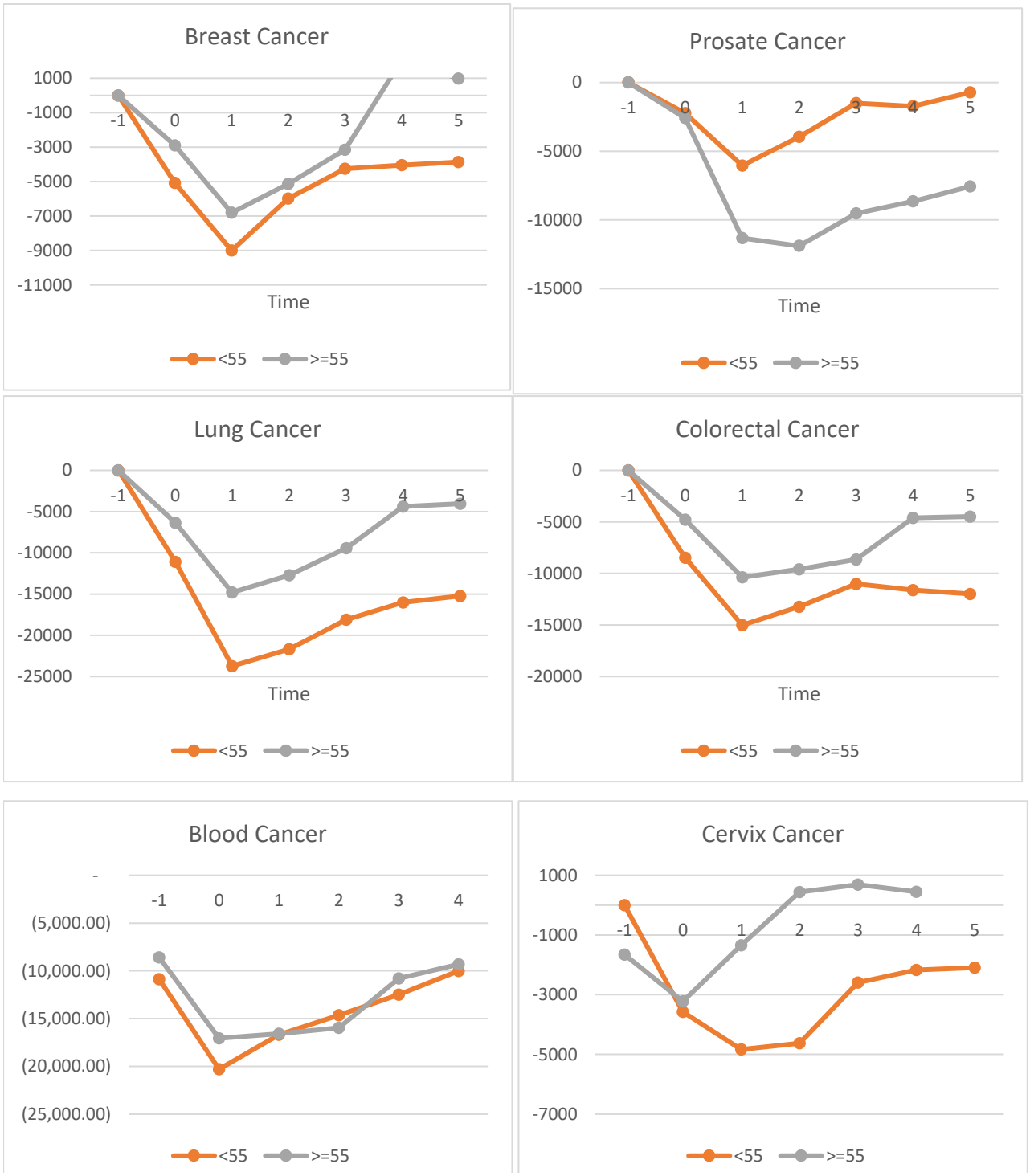
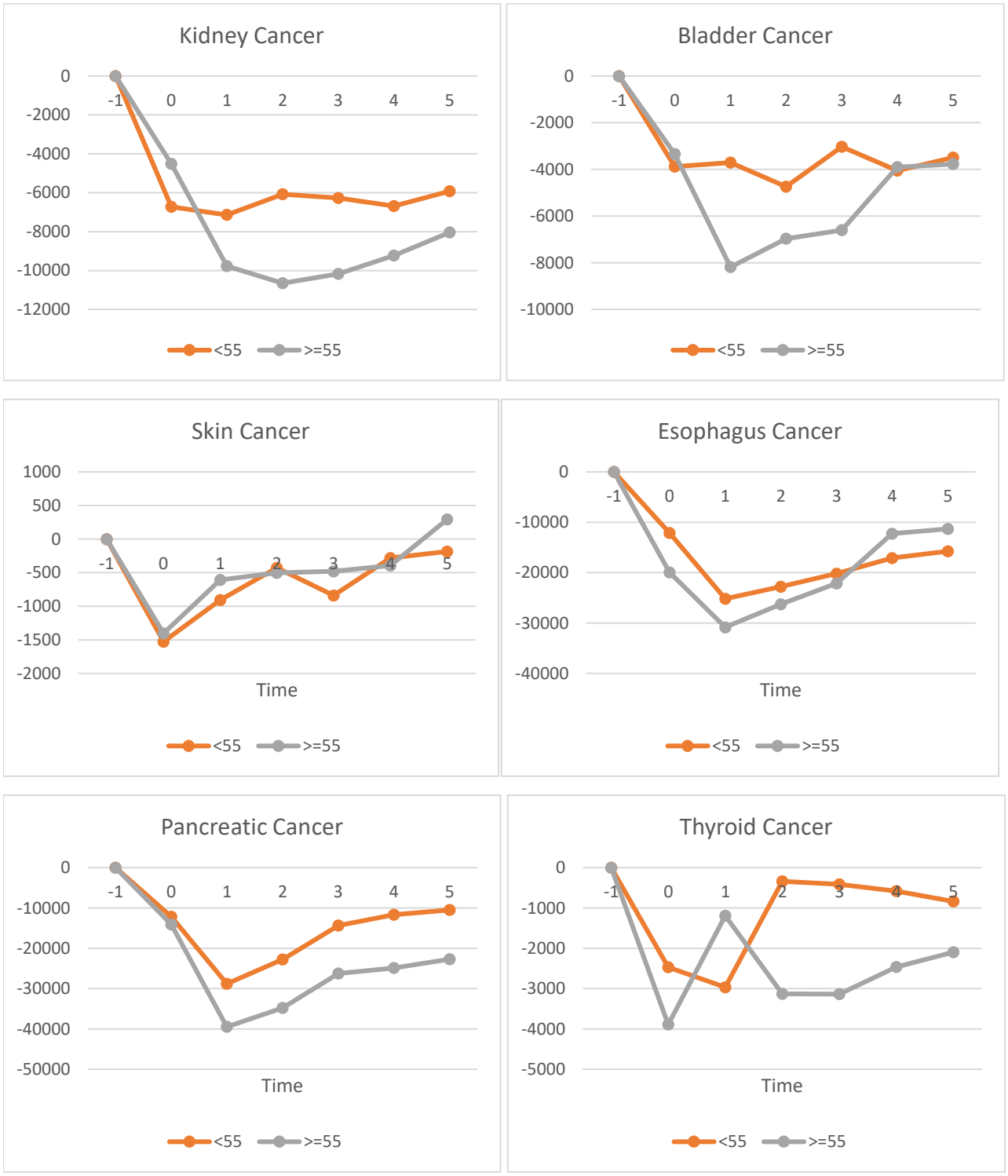


Figure 5. Change in annual labour market earnings ($) by cancer type





Notes; The time period of cancer diagnosis is $t = 0$

- < 55 refers to individuals aged less than 55 at the time of cancer diagnosis
- ≥ 55 refers to individuals aged greater than or equal to 55 at the time of cancer diagnosis

Source: 1991 Canadian Census Health and Environment Cohort (CanCHEC)

Appendix 1. Description of each data source

Census

Population characteristics were primarily drawn from the 1991 Census of Population, version 2B/2D (long-form). The long-form census is administered every five years to provide a comprehensive statistical portrait of Canada's population. Due to its size and scope, the long-form census was unique in its ability to provide reliable data at very small levels of geography and produce indicators for very specific subsets of the population. The 1991 Census was conducted on 4 June 1991.

The census analytic file includes all variables available on the 1991 Census 2B/2D micro-data analytic file.

Canadian Cancer Database (CCDB)

Variables measuring the incidence of cancer were obtained from the Canadian Cancer Data Base (CCDB). The CCDB is a historic file created and used in Statistics Canada, Health Statistics Division and prepared from data received by the National Cancer Incidence Reporting System (NCIRS), 1969 to 1991 and the Canadian Cancer Registry (CCR), 1992 onwards (Carpenter et. al. 2008). The CCDB was created to allow for long-term follow-up on a national scale for research studies to satisfy the demand for information on delayed health risks. At the time of linkage, the CCDB contained cancer incidence events from 1969 to 2003. Each year of cancer incidence data adds about 125,000 records to the database. These cancer incidences are reported to Statistics Canada by all the provincial and territorial Cancer Registries in Canada. Variables included in the analytic file include diagnosis of primary site including morphology and topography, date of diagnosis, and demographic variables.

Canadian Cancer Registry (CCR)

In 1992, the person-oriented Canadian Cancer Registry (CCR) evolved from the event-oriented National Cancer Incidence Reporting System established in 1969. The CCR is an administrative database. Beginning with cases diagnosed in 1992, cancer incidence data collected by provincial and territorial cancer registries (PTCRs) have been reported to the CCR, which is maintained by Statistics Canada.

The CCR is a collaboration between the 13 Canadian PTCRs and the Health Statistics Division of Statistics Canada, where the data are maintained. Ultimate authority and responsibility for the completeness and the quality of the data reside with the provinces and territories. The data that comes into the CCR describes both the individual with the cancer, and the characteristics of the cancer.

The CCR is a dynamic database of all Canadian residents, alive or dead, who have been diagnosed with cancer since 1992. The CCR is a patient-based system that records the type and number (incidence) of primary cancers diagnosed for each person until death. Subsequent primary cancers occurring for patients who are already in the database are linked to their existing patient information. The advantage of this system is that longitudinal data is available for each cancer patient. The patient data is regularly linked to mortality data (death clearance) to optimize the accuracy of date, cause, and place of death fields in the CCR and to identify potential primary cancers not currently registered in the CCR. Since patients' records remain active on the CCR until confirmation of their death, survival rates for the various forms of cancer can be calculated.

This linkage used the February 2014 CCR tabulation file. World Health Organization, International Classification of Diseases for Oncology, Third Edition (ICD-O-3) and the International Agency for Research on Cancer (IARC) rules for determining multiple primary

types (source: International Agency for Research on Cancer, World Health Organization, International Association of Cancer Registries, and European Network of Cancer Registries. International Rules for Multiple Primary Cancers, ICD-O Third Edition, Internal Report No.2004/02. Lyon: International Agency for Research on Cancer, 2004) were used. Please see the footnotes for CANSIM table number 103-0550 for more information on the CCR.

Canadian Mortality Database (CMDB)

Variables measuring the incidence of mortality were obtained from the Canadian Mortality Database (CMDB). The CMDB contains data on deaths occurring in Canada from the year 1950 to the present. Deaths are reported annually by the provincial and territorial Vital Statistics Registries in Canada. This information is extracted from administrative files. Provincial and territorial Vital Statistics Acts (or equivalent legislation) make it mandatory for provinces and territories to register all live births, stillbirths, deaths and marriages occurring within their jurisdiction. These data are provided to Statistics Canada for further analysis.

Historical Tax Summary File (HTSF) and T1 Personal Master File (t1 PMF)

The Historical Tax Summary File is a list of individuals who filed taxes by tax year. This file was used to obtain variables (e.g. names, marital status, postal codes, date of death for those deceased) needed for probabilistic linkage to the CMDB, CCDB and CCR. Postal code by tax year and last tax year filed were retained in the analytical file.

Chapter 4. Health Utility Index, Life Expectancy, and Health Adjusted Life Expectancy for the individuals with cancer in Canada

Preface

While many governmental reports and studies estimate the health profile of the general population, there are relatively few that estimate the health profiles of individuals with chronic conditions, especially those with cancer. This chapter addresses this gap and contributes to the area of research exploring the impact of cancer on health, and extending the investigation by looking at the differing health of individuals with cancer by cancer type.

I, Young Jung, was responsible for conceptualizing the research questions and design, and for completing data analysis. Dr. Christopher Longo provided input on research questions and approaches to study design. Research design, analyses, and interpretations of the study's findings occurred through ongoing conversation with Drs. Christopher Longo and Emile Tompa. I drafted the thesis chapter, and both supervisors provided feedback on the draft that were incorporated into the final version of the chapter. These analyses were undertaken using micro datasets housed in FRDC at Statistics Canada, Ottawa, Canada.

Ch.4 Health Utility Index, Life Expectancy, and Health Adjusted Life Expectancy for the individuals with cancer in Canada

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Abstract

Objective: To estimate the health profile of Canadians with cancer by cancer type.

Methods: Using a linked dataset, we estimated the health profile of individuals with cancer by using three health indicators—life expectancy (LE), the Health Utility Index (HUI), and health-adjusted life expectancy (HALE).

Results: Overall, individuals with cancer are projected to have poorer health across all three health indicators. We found an inverse correlation between health and the severity of cancer, where the individuals with colorectal cancer were estimated to have the lowest health measured by HALE, as they were expected to spend just 56% of the remaining years in good health from the age 35.

Conclusions: We found a statistically significant difference in future projected health between individuals with and without cancer, which suggests the importance of developing disease-specific health indicators.

Introduction

Assessments of the health profile of the population play a vital role in the planning, delivery, and evaluation of the effectiveness of health interventions. Because the justifications for health services interventions rest on their impact on people's health, there must be standard and agreed-upon methods for characterizing and assessing changes to health over time, both at a general population and disease-specific level. Over the past few decades, efforts to develop methods to assess mortality, morbidity, and quality of health have resulted in the availability of instruments—life expectancy (LE), the Health Utility Index (HUI), and health-adjusted life expectancy (HALE)—that are now in widespread use (WHO 1998). However, there have been few comparable developments for individuals with cancer, and the tools that have been developed have not been widely applicable. At least part of the reason for this has to do with the technicality of the literature informing the construction, and a paucity of studies that have used alternative approaches for individuals with cancer.

In many developed and developing countries, the health profile of the population has long been assessed by looking at mortality, using LE as the only measure. Despite its usefulness as a summary indicator of mortality, LE alone is not sufficient to measure the health profile of the population, as approximately 44% of Canadians over 20 years of age are living with at least 1 chronic condition (Roberts et al., 2015), and cancer accounted for 30% of all deaths in 2009, a leading cause of mortality and morbidity (Statistics Canada, 2009). Also, an increased survival rate from 53% in 1992/94 to 60% in 2006/2008 among the individuals with cancer (Canadian Cancer Society, 2018) adds another layer of complexity to using LE to estimate the health profile of individuals with cancer because, while the individuals with cancer are living longer, they are also at a higher risk of living with less than perfect health.

A method of quantifying morbidity scores into a single measure called the Health Utility Index (HUI) was developed by a group of researchers at McMaster University (Feeny et al., 1992; Feeny et al., 1993). HUI is now the most widely used indicator to quantify health status in population surveys of Canada since 1990. It provides descriptive health profile measures that capture both the severity and burdens associated with the disease. The problem remains that HUI does not provide any directionality on how the health profile of the population is expected to look in the future. Also, cancer-related information is often absent in many population surveys.

In order to better measure and understand the health profile of individuals with cancer, a measure that addresses both the length of life and quality of remaining life to fully characterise the life journey of those with chronic diseases was needed. Sullivan (1971) developed a method that led to the creation of health-adjusted life years (HALE), which could capture both the mortality and morbidity of the population. HALE includes both the quality and length of life, and can be interpreted as the average number of years that a person is expected to live in good health. Due to its simplicity and reliability, the HALE measure was adopted in various countries (Robine and Ritchie, 1991; Mathers et al., 1999), and a number of European countries use HALE to measure general populations' and disease-specific sub-populations' health profiles (Wang et al., 2016). The challenge with estimating HALE for the individuals with cancer is that it requires linked datasets containing both mortality and morbidity information for individuals with cancer, which are often not easily accessible to researchers.

This paper attempts to estimate the health profile of individuals with cancer by utilizing linked datasets that are available from Statistics Canada. The health profile of Canadians with cancer will be estimated using three common health indicators—life expectancy, Health Utility

Index, and health-adjusted life years—with the objective of answering two overarching questions: First, what is the health profile of individuals with cancer in Canada using these three health indicators? Second, how does this health profile differ from those without cancer? This analysis does not aim to rank various health indicators. Instead, it aims to provide a comprehensive analysis of health differences between individuals with and without cancer using these three health indicators. The findings of this analysis should be of interest to researchers and policy makers, all of whom should recognize that the choice of one health indicator may affect the policy priority they give to one disease over another, which can have significant implications for the research and policies they inform.

At the time of the analysis, the authors were not aware of any existing studies measuring or comparing the health profile of populations with and without cancer in Canada using LE, HUI and HALE indicators.

Literature review

Over the past century, Canada has made a remarkable improvement in the health of the general population. From 1921 to 2011, life expectancy (LE) at birth increased from 57.1 to 81.7, a gain of 24.6 years. However, LE showed a smaller gain over the same period when calculated for older age groups. For example, in 1921, the LE of a 55-year-old was 20 years. Fast forward to 2011: a 55-year-old is estimated to live an additional 29 years, a gain of 9 years over the same reference period (Statistics Canada, 2016). Cancer is a prominent factor shaping and influencing current mortality in Canada, accounting for 30% of all deaths in 2009. It is thus a leading cause of both mortality and morbidity (Statistics Canada, 2009). At the same time, the quality of life of individuals with cancer as measured by the HUI has been shown to be lower when compared with those without cancer (Statistics Canada, 2015). This highlights the limitations of LE as an

indicator, as it fails to reflect changes in morbidity, disability, and the health status of the population. This failure is not an oversight but rather a feature of what LE is; it is, by definition, simply the number of years that any person of a given age is expected to live. The World Health Organization (WHO, 1998) acknowledges the limitations of LE, stating that "adding years to life" is an empty victory without "adding life to years." In doing so, the WHO recommends using a different indicator that includes both the quantity and quality of health. Studies on longevity and health reaffirm the WHO's claim by concluding that positive tendencies of prolonged life were not accompanied by similar trends in the extension of a healthy life (Rogers et al., 1990; Vebrugge, 1984).

The development of the Health Utility Index (HUI) and its incorporation into periodic surveys in Canada began in 1991. The HUI is one of the utility score indicators recommended by the Canadian Agency for Drugs and Technology in Health in its 2017 guideline. Utility scores are a simple, composite measure to represent the excess burden associated with a given health condition as compared to healthy individuals.

Mittman et al. (1999) used individual level data from the 1994/1995 National Population Health Survey to map out and estimate the variations in the Health Utility Index across 20 chronic conditions in Canada. The authors found that individuals with cancer showed a large gap in HUI when compared to individuals without chronic conditions: individuals with cancer had an HUI of 0.80 and 0.82 for males and females respectively. Compared to the general population without any chronic conditions, there was a difference of 0.13 for males and 0.11 for females in HUI scores. The authors also investigated the differences in HUI scores across age groups and found the smallest difference in the age group of 12 to 19 (a difference of 0.02 between the individuals with and without chronic conditions in this age group) and the largest difference of 0.23 for the age

group 80+. Bowker, Pohar, and Johnson (2006) used the 2000/2001 CCHS to compare the HUI differences among individuals with and without diabetes and/or cancer. Using the weighted ANCOVA method, the authors had similar findings to Mittman et al. (1999), concluding that the population with cancer had a lower HUI than the reference group without chronic conditions (a difference of 0.11 HUI).

Despite being a relatively new population health indicator compared to the others discussed here, health adjusted life expectancy estimates have helped to illuminate the burden of disease attributable to risk factors (Ezzati et al., 2003; Melse et al., 2000). Researchers have likewise discovered an inverse correlation between HALE and socioeconomic status. Bossuyt et al. (2004) found that a lower level of education resulted in more years in poor health, which, in other words, means that those individuals spent fewer years in good health overall. Using a modified Sullivan method, the authors found a difference of 17 years in HALE between the highest and lowest levels of education when predicting remaining HALE for the male population at age 25. For the female population, the HALE difference was 11.42 years.

Van Oyen et al. (2011) found that the HALE difference across different levels of education increased from 1997 to 2004. For example, comparing HALE scores for individuals in the highest and lowest levels of education in a general population, the authors found a difference of 17 HALE in 1997 and 18.58 HALE in 2014. Using administrative datasets, Lee et al. (2016) found that both LE and HALE increased from 2005 to 2011 but found a consistent gap between LE and HALE (HALE is lower by 11.8 for males compared to LE, and 15.5 for females), which implies that the mortality of the population decreased, while the health of the population remained relatively the same.

We found three studies that used HALE in a Canadian context. A study by McIntosh et al. (2009) used the 1991–2001 Canadian mortality database and the Canadian Community Health Survey 2000/2001 to investigate the socioeconomic gradient based on HALE. The researchers compared individuals in high-income deciles to individuals in low-income deciles and found a large difference in HALE at age 25. The difference was substantially larger than if LE alone was used. For example, men aged 25 had a difference of 14.1 years in HALE, whereas with LE the difference was only 7.4. Women had a difference of 9.5 years in HALE and 4.5 in LE between the highest and the lowest income decile. In another Canadian study, Manuel, Schultz, and Kopec (2002) looked at HALE among Ontario residents with chronic diseases. The authors found a difference of 1.7 years in HALE between males with chronic disease and those without chronic disease, and 1.5 years for females. Among individuals with heart disease, the difference was 1.2 for both males and females. Individuals with cancer represented the highest burden of disease, with a difference of 2.9 HALE for both sexes. In a later study, Manuel and Schultz (2004) considered the burden of disease for people with diabetes in Ontario and found a HALE difference of 2.7 and 3.2 for men and women respectively.

An overview of the existing literature indicates that the health profile of the individuals with cancer looks vastly different depending on the methods and indicators used. In order to provide consistent and reliable comparisons of the health profile of Canadians with and without cancer, our study first provided and executed a step-by-step methodology to compute LE, HUI, and HALE. We then investigated the underlying relationship between health and sociodemographic factors using HUI. Finally, we estimated the difference in health across different cancer types. The cancer types included in our study are breast, colorectal, and prostate cancer.

Data sources

A brief description of the datasets used for our study is provided in this section. Full information about the datasets can be found in Appendix 1. The 1991 Canadian Census Health and Environment Cohort dataset contains variables measuring population characteristics, cancer incidence, and mortality. These variables were obtained from the Canadian Cancer Registry and Vital Statistics. Once cancer-related information was identified using the two datasets mentioned above, observations were merged with the Canadian Community Health Survey using a unique identifying variable.

Canadian Cancer Registry and Vital Statistics

The Canadian Cancer Registry (CCR) is an administrative dataset that contains annual cancer-related information on incidence, cancer type, severity, and survival information. The CCR is a dynamic dataset, and thus, once an individual is identified in the CCR, they will continue to be included until their death. Cancer cases are defined based on the International Classification of Diseases for Oncology, Third Edition (Fritz et al., 2000) and classified using the Surveillance, Epidemiology, and End Results (SEER) program grouping definition (Altekruse et al., 2010). The cancer-related mortality observations are confirmed by record linkage to the Canadian Vital Statistics Death Database, which includes demographics and underlying cause of death information.

Canadian Community Health Survey

The Canadian Community Health Survey is an annual cross-sectional survey which contains information on health status, health care utilization, and health determinants for the Canadian population. The CCHS began in 2001 and was repeated every two years until 2005. Beginning in

2007, data was collected annually for the CCHS. The target population of the CCHS includes individuals over the age of 12 who reside in Canada's ten provinces and three territories. Exclusion criteria are individuals living on reserves, Canadian Armed Forces members, and institutionalized populations. The excluded population represents approximately 3% of the Canadian population.

In 2015, a new data collection strategy was implemented for CCHS, and thus caution should be taken when comparing data from pre-2015 to data post-2015. For this reason, our study used the 2014 Canadian Community Health Survey for our analysis. In particular, we estimated HUI using data from that survey year. Control variables developed from the survey include race, education level, marital status, chronic conditions, and total annual income.

Methods

We employed a prevalence-based estimation method as it has been proven to provide a reliable estimate for measuring the health of a population, particularly sub-populations with chronic conditions such as cancer if there is no sudden change in disease prevalence or mortality rate over an extended period of time (Wilkins et al., 1983; Mathers and Robune, 1997). This has been the case for individuals with cancer in Canada. This method is also the preferred approach among epidemiologists and health economists to monitor the change in the health of the population (Romero et al., 2005; Mittman et al., 1999), and the main method used by the World Health Organization (WHO, 1998).

Cancer types

Cancer type information was derived from the Canadian Cancer Registry. However, no information was available regarding the severity/stage of cancer. All cancer type was identified according to the Surveillance, Epidemiology, and End Results grouping for International Statistical

Classification of Diseases (ICD-9) and International Classification of Diseases for Oncology (ICD-O-2/3). In this study, we estimated health profiles across three cancer types—breast, colorectal, and prostate – since the HUI is only observed for the aforementioned cancer types. Additionally, we undertook analysis of individuals with breast, colorectal, and prostate cancer only for the age group 35+, as the aforementioned cancer type is primarily a late onset disease (Leitzmann and Rohrmann, 2012).

Measuring life expectancy

We used life table methodology to estimate life expectancy, probability of death, and probability of survival between age groups. The construction of a life table allowed us to summarize mortality within a population at a given time or within a cohort. Accordingly, the life table methodology meets the rigours of various statistical needs, particularly in the fields of health and actuarial science, as it facilitates comparison between groups.

Our study used a linked Canadian Cancer Registry and Vital Statistics to identify the number of deaths due to cancer. Using population estimates from Statistics Canada, we identified the size of the population in the calendar year of 2013/2014. We chose to focus on a target population comprised of individuals with cancer and individuals without cancer up to the age of 85, since the cause of death in older age groups could also be due to age as opposed to their condition, and thus it is impossible to identify a clear cause of death using the linked datasets.

The main indicator, q_x, represents the probability of death within a specified time period, specifically, over a decade. Specifically, q_x is the ratio of the number of deaths within each age group as a proportion of the size of the population from which these persons belong (e.g., 25 to 34 years old). The probability of death was calculated using the following equation,

$$q_x = \frac{l_x - l_{x+10}}{l_x} = \frac{d_x}{l_x}$$

Where:

- q_x refers to probability of death
- l_x refers to the number of survivors
- d_x refers to the number of deaths

Life expectancy (LE_x) of individuals with cancer is the ratio between the sum of total years ($\sum_{i=x}^{w} L_i$) that individuals with cancer have survived when reaching a given age X compared to the number of persons who have survived to the of age X. It is calculated according to the formula:

$$LE_x = \frac{\sum_{i=x}^{w} L_i}{l_x}$$

Health Utility Index Mark 3

The Health Utility Index Mark 3 (HUI) is a key input into the calculation of HALE. The HUI is a utility-based, multi-attribute health classification measure, which represents a summary value of an individual's health with a single number within a continuous index between -0.36 (the worst possible health state) through 0.0 (dead) and 1.0 (perfect health), based on preference scores for different health states (Torrance et al., 1995). There are eight different attributes of health: vision, hearing, speech, mobility, dexterity, emotional state, cognition, and levels of pain and discomfort (Torrance et al., 1995), each with five or six levels. These are described in Appendix 2. The abovementioned eight attributes were combined using preference scores from the HUI Mark 3 using the following multi-attribute utility function:

$$u = 1.37\ (u_1 \times u_2 \times u_3 \times u_4 \times u_5 \times u_6) - \ 0.371 \qquad (3)$$

The mean HUI scores from the 2010 and 2014 CCHS were estimated for individuals with and without cancer stratified by sex, age groups (25–34, 35–44, 45–54, 55–64, 65–74, 75–84, 85+), education attainment, and income level. Survey weights were applied so that the mean HUI estimates were representative of the health status of the underlying target populations by sex and age group. Additionally, bootstrap weights were applied so that the standard error was estimated, taking into account the survey's complexity.

To deal with outliers in the HUI distribution, we dropped observations below the 1st percentile or above the 99th percentile of the HUI distribution for each sex and age group, following the Statistics Canada's guideline (Statistics Canada CCHS, 2014). Individuals who had missing HUI variables were excluded from our analysis.

Chronic conditions

We compared the difference in HUI scores between the individuals with cancer and those without cancer, controlling for a number of chronic conditions at the time of the survey as many individuals with cancer are known to have multiple chronic conditions (Mittman 1999). Based on chronic conditions identified by Statistics Canada (Statistics Canada, 2017), we included the following chronic conditions in our study: Alzheimer's disease or any other dementia, anxiety, asthma, arthritis, back problems, bowel diseases, cancer, COPD, diabetes, heart disease, high blood pressure, migraine, scoliosis, mood disorder, stomach or intestinal ulcers, stroke, and urinary incontinence.

Health Adjusted Life Expectancy

We utilized a modified version of the Sullivan method (Sullivan, 1971), which is based on the prevalence method, to estimate HALE between individuals with and without cancer in Canada.

We estimated the age-specific probability of death for individuals with cancer using equation 1, which was then incorporated into the life table to estimate the LE of those with and without cancer using equation 2. In order to distinguish the number of deaths and the subsequent probability of death due to cancer from the general population, we used the following equation,

$$R_i = \frac{D_{ai} - D_{ci}}{P_{ai} - P_{ci}} \quad (4)$$

Where:

- R_i refers to an age-specific mortality rate
- D_{ai} refers to the number of deaths from all causes in age group *i*
- D_{ci} refers to the number of deaths due to cancer in age group *i*
- P_{ai} refers to the number of individuals in age group *i*
- P_{ci} refers to the number of individuals with cancer in age group *i*

HALE is based on the standard life expectancy equation derived from the life table but modified with HUI based on equation 5.

$$HALE_x = \frac{\sum_{i=x}^{w}(L_i * H_i)}{l_x} \quad (5)$$

Where:

- x is the reference age for a specific life expectancy or HALE value
- $HALE_x$ refers to health adjusted-life expectancy at age x
- i refers to the lower limit (x) of the age interval (x, x+a)
- L_x refers to the number of years lived in the age group (x, x+a)
- l_x refers to the number of survivors at age x
- H_i refers to HUI scores for the age group (x, x+a)

- *w* refers to the total number of age groups in the life table

Results

Table 1 presents demographic information for the study population. The demographic information includes sex, age groups, marital status, education, immigration status, income group, and presence of cancer. Out of the 98,228 individuals in our dataset, 2,757 individuals were identified as having cancer at the time of the survey. Individuals with cancer were also reported to have 4.04 number of chronic conditions on average, as compared to 3.56 chronic conditions for individuals without cancer.

[Insert Table 1 here]

Health utility index

Table 2 shows the distribution of mean HUI by age groups and sex. Owing to the decrease in general health status with advancing age, we found that HUI estimates decreased with age. The individuals with cancer showed a lower level of HUI compared to those without cancer. Focusing on individuals with cancer, males with cancer showed slightly lower HUI estimates (0.73 in 2014) compared to females (0.81 in 2014) for the age group 35–44. In both survey years, individuals with cancer in the age group 45–54 had a 0.10 lower HUI in 2010, and 0.15 lower in 2014 compared to individuals without cancer, looking at both sexes.

[Insert Table 2 here]

Tables 3 shows the estimates of HUI by income levels for both individuals with and without cancer. Overall, there was a positive correlation between income and health measured by HUI; the highest HUI was observed for the individuals with cancer in the second highest income group ($60,000 to $79,999) at 0.85 in 2010 and 0.81 in 2014. Table 4 shows the estimates of HUI by

education level for both individuals with and without cancer. Individuals with higher education were found to have higher HUI compared to those with less than secondary education. Unlike the estimates we observed in Table 3, we noticed a positive correlation between education and HUI throughout all levels of education.

[Insert table 3 here]

[Insert table 4 here]

We identified two key patterns from the estimates in Tables 3 and 4. First, controlling for both levels of education and income, we found more pronounced differences in HUI across the income groups than we did for the education levels when comparing individuals with cancer and those without cancer. Secondly, the females with cancer showed the largest difference in HUI compared to those without cancer, even after controlling for education and income level. In other words, the impact on qualify to life of a cancer diagnosis may be more pronounced for the females with cancer compared to the males with cancer.

Estimates of HUI for three cancer types – breast, prostate and colorectal

We observed a clear inverse correlation between HUI and age for individuals with breast cancer, where the HUI decreased as the individuals with breast cancer got older (shown in Table 5). The HUI differences between the individuals with breast cancer and their counterparts were marginal: the individuals with breast cancer had a lower HUI by 0.06 compared to individuals without cancer for the 45–54 age group in 2014.

Table 6 shows a clear positive correlation between income and HUI estimates, where the HUI estimates increase as the income level goes up. Comparing the estimates between individuals with and without cancer, we observed the largest difference with the $80,000+ income group,

where the individuals with breast cancer had a lower HUI by 0.16 in 2010 and 0.13 in 2014 compared to those without cancer. Looking at education levels (Table 7), we also found a positive correlation between education levels and HUI estimates.

[Insert table 5 here]

[Insert table 6 here]

[Insert table 7 here]

We undertook analysis of individuals with prostate cancer only for the age group 45+, as prostate cancer is primarily a late-onset disease (Leitzmann and Rohrmann, 2012) as shown in Table 5. The HUI estimates of the individuals with prostate cancer were similar to those with breast cancer, in that there was an inverse correlation between age and HUI as shown in Table 5. In Table 6, we also observed a positive correlation between HUI and income level. However, the individuals with prostate cancer had negligible and, at times, no differences in HUI compared to individuals without cancer in 2014. This pattern was also observed across the education levels in Table 7.

Of the three cancer types—breast, prostate, and colorectal—that we considered, colorectal cancer is considered the most severe in terms of its 5-year survival rate, and this is reflected in the HUI estimates. In Table 8, the individuals with colorectal cancer had the lowest HUI for age group 75 to 84 for both sexes: a difference of 0.08 when compared to individuals without cancer in 2014. As was also observed with other cancer types, in the 55 to 64 age group in 2014, the females with colorectal cancer had an HUI lower than those without cancer by 0.13, while the males with colorectal cancer had a lower HUI by 0.05 in comparison to their counterparts without cancer.

[Insert Table 8 here]

Both income and education level showed a positive correlation with HUI estimates, where a higher level of income or education was correlated with higher HUI. The results are shown in Tables 10 and 11.

[Insert Table 9 here]

[Insert Table 10 here]

Individuals with multiple chronic conditions

Researchers have found that people with cancer are twice as likely to have high blood pressure, high cholesterol, or diabetes as healthy people without cancer. Hence, it was imperative to control for the number of chronic conditions in our study and to estimate the impact of having an additional chronic condition on both individuals with and without cancer. Table 11 shows that many individuals with cancer live with multiple chronic conditions, and we found a statistically-significant correlation in which a prevalence of more chronic conditions is associated with lower HUI estimates.

[Insert Table 11 here]

Life expectancy and health-adjusted life expectancy

HALE estimates for all cancer types across the age groups are shown in Table 11. Columns 2 to 4 from the left side of the table illustrate the layout of the life table necessary for the calculation of LE and HALE. The LE of individuals without cancer at age 25 was 54.85, compared to 27.27 for those with cancer. Looking at the HALE calculations, individuals without cancer showed a HALE of 49.27 at age 25, compared to 21.21 for the individuals with cancer. In other words, at the age of 25, individuals with cancer were expected to spend 77% of the remaining time in good

functional health, whereas individuals without cancer were expected to spend 89% of the remaining years in good functional health.

Table 12 shows the LE and HALE for individuals with prostate cancer. The LE of the individuals with prostate cancer was 19.11 at age 45, compared with 34.56 for those without cancer. HALE was estimated at 15.99 for individuals with prostate cancer, and 29.95 for those without. For the age group of 85, there was no difference in LE between the two groups, and the difference in HALE was estimated at 0.39. We found similar results for individuals with breast cancer, which can be found in Table 13.

[Insert table 12 here]

[Insert table 13 here]

Table 14 shows the estimates of LE and HALE for individuals with colorectal cancer. We observed the largest difference in HALE compared with three other categories—breast, prostate, and all cancer types. This might be related to the poor prognosis that the individuals with colorectal cancer face. At the age of 35, LE for individuals without cancer was 45.62 years, compared with the estimate of 14.47 for the individuals with colorectal cancer. Looking at HALE estimates, the individuals with colorectal cancer showed 13.44 at age 35 compared to 40.73 for those without cancer, which resulted in a difference of 27.28. To sum this up, individuals with colorectal cancer were only expected to spend 56% of their remaining years in good health at age 35, whereas individuals without cancer were expected to spend 85% of the remaining years in good health.

Discussion

One of the first steps of the WHO's healthy project (WHO, 2016) was to develop a comprehensive health profile that describes the health of the population of interest, bringing together key pieces of information on health and its determinants. With that in mind, we set out to measure the health of Canadians with cancer while raising important methodological questions about how to estimate the health of the population, particularly those with cancer. We used LE, HUI, and HALE as health indicators to measure the health of individuals with cancer and presented the findings across different types of cancer.

Life expectancy was the first health indicator we used to estimate the health of the individuals with cancer in Canada as it is a standard indicator for estimating the health of the population in many developed countries, its methodologies are well defined, and it is largely non-controversial (Egidi and Spizzichino, 2008). The LE at birth for the general population in Canada for both sexes has increased steadily but has showed signs of slowing down in recent years. For example, life expectancy at birth increased only by 1.8 years from 78.1 in 2005/2007 to 79.9 in 2014/16 (Statistics Canada, 2016), despite increasing health care spending per capita by 50% from 2005 to 2016 (CIHI, 2018). Profound and persistent disparities across different chronic diseases are the primary drivers of the decelerated improvement in life expectancy (Cullen, Cummins, and Fuchs, 2012; Wang et al., 2013). This was exemplified by the findings of our study, which focused on individuals with cancer. In our study, we found a difference of 39.06 LE at birth, which suggests that individuals without cancer were expected to live twice as long compared to individuals with cancer (LE of 79.07 compared to LE of 40.01), with the same difference observed for the age group 65–74.

In order to improve the life expectancy of the Canadian population, there needs to be a shift in approach from the longstanding focus on medical intervention to behaviour, environment, health and social determinants that contribute to LE. Accordingly, public health officials have echoed the same concern and called for a development of disease-specific LE indicators to drive policy initiatives to address the underlying determinants of health (DeSalvo et al., 2016). Without valid and reliable disease-specific life expectancies, health officials are restricted in their ability to detect disparities and identify underlying health determinants. Disease-specific LE can assist health officials in allocating scarce healthcare resources to targeted objectives, and in evaluating the effects of interventions designed to improve the health of the population.

The Health Utility Index (HUI) was the second health indicator we used to measure the health of individuals with and without cancer. There were three key findings which required further explanation. First, we found a positive correlation between income levels and HUI for both groups across all types of cancer. This finding of our study reinforces the idea that income is an important determinant of health with the individuals with cancer being no different (McLeod et al., 2003; Xi et al., 2005and equally as affected.). Second, we found a positive correlation between education and HUI for both individuals with and without cancer. This finding reaffirms previous findings regarding the protective effects of education, wherein health increases with education (Cutler and Lleras-Muney, 2006). The explanation based on the human capital model (Grossman 2000) is that more education is related to higher income, so that individuals value their health more due to the monetary values associated with it. Alternatively, it might be that higher levels of education lead, or are tied, to different decision-making patterns, and hence the individuals with cancer are better prepared to anticipate and adapt to their changes in health due to cancer. Finally, we observed heterogenous effects of cancer types, in which we found that a lower HUI was associated with

more severe type of cancer, such as colorectal. This finding shows that not all individuals with cancer experience equal suffering and supports calls for future research to differentiate cancer types, as the various cancer types can have disparate implications for health outcomes and needed resources.

One of the objectives of this paper was to provide a catalogue of the health utility scores for various cancer types across different sociodemographic characteristics based on a representative Canadian population dataset. With an increase in emphasis on evidence-based decision-making processes and the involvement of the health technology assessment (CADTH, 2017) using HUI in healthcare priority settings, having a list of health utility scores for individuals with cancer helps facilitate economic analyses, especially when health utility scores are being used as a centerpiece in many cost-utility analyses.

The third health indicator employed in this study, HALE, is a morbidity-mortality indicator that summarizes information on the quantity and quality of the years expected to live. Our study found a wide range of HALE estimates across cancer types. For all cancer types we found that individuals with cancer had a lower HALE by 27.98 at age 25 compared to those without cancer. This finding is closely aligned with the Public Health Agency of Canada's (2012) finding of a 33.3 HALE difference for females, and 34.8 for males at age 20 when, compared to individuals without cancer, which lends credence and validity to our results. The difference in the findings may stem from the use of the most recently available data sources and the inclusion of more comprehensive cancer types in our study.

Another key finding of our study was the correlation between HALE and the severity of cancer, with differences of 20.84 HALE for colorectal cancer, 17.95 HALE for breast cancer, and 13.96 HALE for prostate cancer at the age of 45 when compared to individuals without cancer.

The findings suggest that individuals with the more severe types of cancer, according to the 5-year survival rate, spend less time in good health as compared to those without cancer. As our study is the first to estimate HALE by cancer types, we did not find any other published literature to support our findings. However, looking beyond the cancer literature, Romero et al. (2005) found an association between lower HALE estimates and more severe types of disability, which indirectly supports our findings.

Health Canada's health indicators report (Health Canada, 2012) outlines various objectives, two of which are addressed by this paper: 1) to develop a framework of health indicators that can be compared across 14 jurisdictions and address health disparities, and 2) to make informed decisions about health care and share best practices across jurisdiction. HALE, by definition, is an appropriate indicator for the first goal and is an excellent indicator for estimating disparities. The decomposition of HALE into the specific conditions that lead to mortality and morbidity illustrates the utility of the composite measure, providing important insights into how to improve overall HALE, identifying health problems that may be neglected, and highlighting the strengths and weakness of the existing health information system. Using HALE as one of the main indicators to estimate the health profile of individuals with cancer may cause a shift in investment away from health care interventions that do not contribute to HALE—including many high-intensity interventions near the end of life that individuals with cancer do not necessarily value—to the broader social and environmental determinants of health that individuals with cancer do find important.

Use of composite measure such as HALE can help us to facilitate comparisons within and across population. The public health agency of Canada report (2012) indicate that at age 20, the loss of HALE was greater for individuals with diabetes (female: 10.1 HALE; male: 9.6 HALE),

compared to individuals with hypertension (female: 6.1 HALE; male: 5.7 HALE). Our findings indicate that individuals with cancer suffer the largest loss of HALE - at age 25, the loss of HALE was 27.98 for both sexes. By focusing on the area that has the most room for improvement, HALE can be used to estimate the quantitative health benefits from interventions and serve as a tool to assist in the allocation of scarce health care resources and plan efficient health care systems. Also, the use of HALE as one of the main health indicators would determine whether Canadians, while adding years to life, have likewise been adding life to years.

One of the possible reasons for the difference between LE and HALE is the increased burden of chronic diseases due to a growth in incidence rate combined with an increase survival rate among individuals with cancer. In order to improve HALE among individuals with cancer, health initiatives need to be focused on not just reducing mortality but also on reducing the incidence and prevalence rates of chronic diseases such as cancer. To do so, primary prevention for chronic diseases should be strengthened. Additionally, further research is needed in order to investigate the underlying factors that influence the differences between LE and HALE among individuals with cancer. To achieve the last goal, the health profile of the individuals with cancer using HALE needs to be estimated on a regular basis to identify and then monitor influential factors such as chronic conditions, health behavior, and socioeconomic factors.

The major strength of this study lies in our ability to estimate LE, HUI, and HALE for Canadians with cancer by cancer type. In addition, we were able to distinguish healthy years lived from the total number of years lived. Following the methodologies provided and the annual update of CCHS dataset, researchers can use this study to provide more up-to-date information on the health of Canadians with cancer, and expand its scope to other chronic conditions.

Limitations

One limitation of our study, associated with the use of the Canadian Cancer Registry dataset, is missing diagnosis dates on some of the registry data, as well as the absence of data for the 85+ age group. About 5% of the cancer records had missing observations for the date of diagnosis, which prevented us from estimating the survival time and thus the probability of death. Due to the annual update of the dataset, it was difficult to discern the cause of death for older age groups (85+).

The cross-sectional nature of the CCHS limited us to utilize the prevalence based estimation method and hence the health outcome estimates represent individuals with cancer at a point in time and prevented us from claiming the directionality of the relationship between cancer and HUI over time. Even though much of the analysis in this paper discussed health profile patterns over age groups and sex, this should not be interpreted to refer to the dynamics of health status over time as health of individuals with cancer may change over time. For example, the health of individuals may show a lower HUI estimate following the initial cancer diagnosis and may show a sign of recovery after the successful treatment, but this could change if individuals were to experience recurrence of cancer.

We were not able to differentiate cancer stages across cancer types in our analysis. Based on the SEER STAT (National Cancer Institute, 2010), different stages of cancer within the same cancer type can have a wide range of prognoses. It is possible that our HUI estimates may not accurately represent individuals with cancer due to the lack of observation on cancer stages and their distribution across our sample.

The HUI estimates in this study should be interpreted with caution, especially if compared to other commonly used health indexes—EQ-5D and SF-6D—as the health state values can vary widely depending on the instruments used. For example, comparing the mean health state values for individuals with spine disorder, McDonough et al. (2005) found the mean value of 0.30 for EQ-5D, 0.22 for HUI, and 0.11 for SF-6D. At this point, there is no consensus on how to standardize the utility values across different indexes, and no indication as to which indices provides the most reliable measure for a particular health condition.

Conclusion

In this paper, we presented quantitative results outlining the difference in life expectancy, health utility index, and health-adjusted life expectancy between individuals with cancer and without cancer in Canada. The most important finding is that we found a correlation between the severity of cancer and health profile, where a population with a more severe type of cancer, in terms of 5-year survival rate is shown to have lower health measured by all three health indicators. We also observed lower health profiles for the individuals with cancer across different socioeconomic status where cancer population in a lower income group are shown to have lower health profile compared to the individuals with cancer in a higher income group.

The objective of this study was to provide estimates of the health profile for Canadians with cancer using three commonly used health indicators—LE, HUI, and HALE—thus starting discussions around the various indicators used to measure the health of the population and how we can utilize the aforementioned indicators to highlight the disparities between individuals with and without cancer. We cannot presume to suggest or outline the myriad processes required to shape public health policies to reduce this difference, but we hope to contribute to the literature and provide policy-relevant information by estimating disease-level results while controlling for

different socioeconomic characteristics so that policymakers can use the relevant and up-to-date information to allocate scarce healthcare resources to reduce the inequality among cancer populations.

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Table 1. Demographic information from CCHS 2014

Variable	N	Frequency (%)
Sex		
Male	43,557	44.34
Female	54,671	55.66
Cancer		
Yes	2,757	2.81
No	95,312	97.03
Not stated	21	0.16
Age group		
15-24	6,824	6.95
25-34	12,454	12.68
35-44	13,094	13.33
45-54	13,946	14.2
55-64	21,246	21.63
65-74	17,310	17.62
75-85	5,679	5.78
85+	7,675	7.81
Marital Status		
Married	43,544	44.33
Common-law	9,147	9.31
Widow/Sep/Divorced	24,247	24.68
Single/Never Married	21,290	21.67
Highest level of education		
Less than High school	17,304	17.62
High school	19,998	20.36
Some Post-secondary	4,613	4.7
Post-secondary	56,313	57.33
Immigration Status		
Immigrant	14,129	14.38
Non-Immigrant	84,099	85.62
Income Group		
No Income	1,765	1.8
Less than 20,000	25,562	26.02
$20,000-$39,999	28,952	29.47
$40,000-$59,999	18,866	19.21
$60,000-$79,999	10,426	10.61
$80,000 or more	12,657	12.89
Number of chronic conditions (not including cancer)		
Cancer	4.04	
No Cancer	3.56	

Source: 2014 Canadian Community Health Survey (CCHS).

Table 2. Health utility index III scores for cancer and non-cancer population by age groups and sex

	2010						2014					
	Both sexes		Males		Females		Both sexes		Males		Females	
Age group	No Cancer	Cancer	No Cancer	Cancer	No Cancer	Cancer	No Cancer	Cancer	No Cancer	Cancer	No Cancer	Cancer
25 to 34	0.92 (0.15)	0.75 (0.22)	0.92 (0.15)	0.75 (0.26)	0.92 (0.15)	0.74 (0.20)	0.90 (0.17)	0.78 (0.30)	0.90 (0.17)	0.80 (0.00)	0.90 (0.16)	0.77 (0.35)
35 to 44	0.90 (0.17)	0.81 (0.26)	0.90 (0.17)	0.68 (0.34)	0.90 (0.17)	0.86 (0.20)	0.89 (0.18)	0.75 (0.33)	0.90 (0.17)	0.73 (0.43)	0.89 (0.19)	0.81 (0.27)
45 to 54	0.87 (0.20)	0.77 (0.28)	0.89 (0.18)	0.83 (0.22)	0.86 (0.21)	0.72 (0.30)	0.86 (0.21)	0.71 (0.29)	0.87 (0.21)	0.61 (0.29)	0.86 (0.21)	0.80 (0.25)
55 to 64	0.85 (0.21)	0.79 (0.25)	0.86 (0.21)	0.79 (0.26)	0.85 (0.20)	0.79 (0.24)	0.84 (0.22)	0.76 (0.28)	0.84 (0.22)	0.72 (0.31)	0.84 (0.21)	0.80 (0.25)
65 to 74	0.84 (0.21)	0.76 (0.27)	0.85 (0.21)	0.74 (0.27)	0.83 (0.22)	0.77 (0.25)	0.84 (0.21)	0.81 (0.22)	0.85 (0.20)	0.82 (0.23)	0.84 (0.22)	0.81 (0.22)
75 to 84	0.80 (0.25)	0.77 (0.26)	0.82 (0.22)	0.76 (0.26)	0.77 (0.27)	0.78 (0.27)	0.79 (0.25)	0.74 (0.27)	0.81 (0.24)	0.79 (0.29)	0.79 (0.26)	0.68 (0.24)
85+	0.69 (0.30)	0.62 (0.34)	0.69 (0.31)	0.64 (0.33)	0.70 (0.30)	0.58 (0.35)	0.70 (0.30)	0.63 (0.33)	0.73 (0.28)	0.66 (0.32)	0.69 (0.31)	0.59 (0.33)
Weighted n	28,303,815	553,277	13,948,884	287,302	14,354,931	265,975	29,569,789	551,491	14,584,120	275,963	14,985,669	275,528

Source: 2010 and 2014 Canadian Community Health Survey (CCHS).

Table 3. Health utility index III scores for cancer and non-cancer population by income level

	2010						2014					
	Both sexes		Males		Females		Both sexes		Males		Females	
Income group	No Cancer	Cancer	No Cancer	Cancer	No Cancer	Cancer	No Cancer	Cancer	No Cancer	Cancer	No Cancer	Cancer
Less than 20k	0.83 (0.25)	0.67 (0.33)	0.82 (0.25)	0.63 (0.36)	0.83 (0.24)	0.70 (0.31)	0.80 (0.26)	0.62 (0.34)	0.80 (0.26)	0.52 (0.36)	0.80 (0.25)	0.71 (0.28)
$20,000 to $39.999k	0.87 (0.19)	0.73 (0.29)	0.88 (0.19)	0.72 (0.27)	0.87 (0.19)	0.73 (0.31)	0.85 (0.21)	0.75 (0.26)	0.85 (0.21)	0.75 (0.27)	0.85 (0.20)	0.76 (0.24)
$40,000 to $59,999k	0.91 (0.16)	0.78 (0.24)	0.91 (0.15)	0.75 (0.25)	0.90 (0.16)	0.83 (0.20)	0.89 (0.16)	0.82 (0.21)	0.89 (0.16)	0.81 (0.20)	0.90 (0.15)	0.83 (0.22)
$60,000 to $79,999	0.91 (0.13)	0.87 (0.22)	0.91 (0.13)	0.87 (0.22)	0.91 (0.13)	0.86 (0.21)	0.91 (0.14)	0.84 (0.23)	0.91 (0.14)	0.86 (0.18)	0.90 (0.15)	0.84 (0.28)
$80,000 or more	0.93 (0.13)	0.85 (0.18)	0.92 (0.14)	0.86 (0.19)	0.93 (0.11)	0.83 (0.16)	0.91 (0.12)	0.82 (0.14)	0.91 (0.28)	0.85 (0.14)	0.92 (0.22)	0.80 (0.14)
Weighted n	21,898,582	446,060	10,925,935	235,495	10,972,647	210,565	23,257,581	463,787	11,527,951	233,565	11,729,630	230,222

Source: 2010 and 2014 Canadian Community Health Survey (CCHS).

Table 4. Health utility index III scores for cancer and non-cancer population by education level

	2010						2014					
	Both sexes		**Males**		**Females**		**Both sexes**		**Males**		**Females**	
Education group	No Cancer	Cancer	No Cancer	Cancer	No Cancer	Cancer	No Cancer	Cancer	No Cancer	Cancer	No Cancer	Cancer
Less than secondary	0.84 (0.23)	0.70 (0.31)	0.85 (0.22)	0.66 (0.32)	0.82 (0.24)	0.74 (0.30)	0.82 (0.23)	0.66 (0.35)	0.83 (0.22)	0.64 (0.36)	0.82 (0.40)	0.68 (0.33)
Secondary grad	0.87 (0.19)	0.73 (0.30)	0.89 (0.17)	0.80 (0.23)	0.86 (0.21)	0.67 (0.34)	0.85 (0.21)	0.74 (0.31)	0.86 (0.21)	0.74 (0.31)	0.84 (0.81)	0.76 (0.29)
Other post-secondary	0.87 (0.20)	0.73 (0.31)	0.89 (0.18)	0.74 (0.31)	0.86 (0.22)	0.72 (0.31)	0.88 (0.17)	0.75 (0.25)	0.89 (0.16)	0.73 (0.27)	0.87 (0.11)	0.77 (0.23)
Post-secondary grad	0.90 (0.17)	0.78 (0.25)	0.90 (0.17)	0.78 (0.27)	0.90 (0.17)	0.78 (0.23)	0.88 (0.18)	0.79 (0.25)	0.89 (0.17)	0.79 (0.25)	0.88 (0.75)	0.79 (0.26)
Weighted n	27,327,323	537,862	13,446,298	279,702	13,881,025	258,160	29,091,126	540,126	14,323,349	270,973	14,767,777	269,153

Source: 2010 and 2014 Canadian Community Health Survey (CCHS).

Table 5. Health utility index III scores for breast and prostate cancer by age group

	2010		2014		2010		2014	
	Breast cancer				Prostate cancer			
Age group	No Cancer	Cancer	No Cancer	Cancer	No Cancer	Cancer	No Cancer	Cancer
35 to 44	0.90 (0.17)	0.96 (0.11)	0.88 (0.19)	0.85 (0.22)	(.)	(.)	(.)	(.)
45 to 54	0.86 (0.22)	0.75 (0.24)	0.86 (0.21)	0.80 (0.08)	(.)	(.)	0.86 (0.21)	0.84 (0.00)
55 to 64	0.85 (0.21)	0.79 (0.18)	0.84 (0.21)	0.83 (0.30)	0.86 (0.21)	0.89 (0.05)	0.84 (0.22)	0.83 (0.12)
65 to 74	0.83 (0.22)	0.78 (0.27)	0.83 (0.22)	0.84 (0.15)	0.84 (0.21)	0.78 (0.36)	0.85 (0.21)	0.82 (0.17)
75 to 84	0.77 (0.27)	0.76 (0.27)	0.78 (0.26)	0.75 (0.12)	0.82 (0.23)	0.77 (0.10)	0.80 (0.25)	0.75 (0.06)
85+	0.72 (0.30)	0.70 (0.22)	0.68 (0.31)	0.64 (0.26)	0.68 (0.31)	0.67 (0.07)	0.72 (0.29)	0.65 (0.36)
Weighted n	14,604,435	25,868	15,254,290	27,489	14,240,469	8,015	14,744,475	9,132

Source: 2010 and 2014 Canadian Community Health Survey (CCHS).
(.) represents missing observation

Table 6. Health utility index III scores for breast and prostate cancer by income group

Income group	2010		2014		2010		2014	
	Breast cancer				**Prostate cancer**			
	No Cancer	Cancer	No Cancer	Cancer	No Cancer	Cancer	No Cancer	Cancer
Less than $20k	0.82 (0.25)	0.76 (0.27)	0.80 (0.25)	0.79 (0.23)	0.82 (0.26)	0.86 (0.10)	0.79 (0.27)	0.65 (0.37)
$20k to $39,999	0.87 (0.19)	0.82 (0.15)	0.85 (0.20)	0.78 (0.27)	0.87 (0.19)	0.80 (0.26)	0.85 (0.22)	0.90 (0.07)
$40k to $59,999	0.90 (0.16)	0.79 (0.22)	0.90 (0.16)	0.76 (0.28)	0.90 (0.16)	0.87 (0.10)	0.89 (0.16)	0.90 (0.10)
$60k to $79,999	0.91 (0.13)	0.80 (0.00)	0.90 (0.15)	0.78 (0.15)	0.91 (0.14)	0.88 (0.03)	0.91 (0.14)	0.92 (0.07)
$80,000 +	0.93 (0.12)	0.77 (0.16)	0.91 (0.15)	0.78 (0.06)	0.92 (0.14)	0.88 (0.06)	0.91 (0.14)	0.91 (0.03)
Weighted n	11,170,272	18,408	11,949,421	23,513	11,159,760	7,725	11,744,475	26,316

Source: 2010 and 2014 Canadian Community Health Survey (CCHS).

Table 7. Health utility index III scores for breast and prostate cancer by education level

Education level	2010 Breast Cancer		2014 Breast Cancer		2010 Prostate Cancer		2014 Prostate Cancer	
	No Cancer	Cancer	No Cancer	Cancer	No Cancer	Cancer	No Cancer	Cancer
Less than secondary	0.82	0.67	0.82	0.65	0.85	0.76	0.83	(.)
	(0.24)	(0.21)	(0.24)	(0.32)	(0.22)	(0.25)	(0.23)	
Secondary grad	0.85	0.68	0.84	0.70	0.89	0.81	0.86	0.80
	(0.21)	(0.33)	(0.22)	(0.17)	(0.22)	(0.25)	(0.21)	(0.29)
Other post-secondary	0.86	0.69	0.87	0.68	0.89	0.82	0.88	0.83
	(0.22)	(0.31)	(0.18)	(0.14)	(0.19)	(0.06)	(0.17)	(0.05)
Post-secondary grad	0.89	0.80	0.88	0.85	0.90	0.90	0.89	0.90
	(0.17)	(0.18)	(0.19)	(0.20)	(0.17)	(0.07)	(0.18)	(0.16)
Weighted n	14,122,744	24,339	15,032,009	25,210	13,727,292	8,015	14,575,593	30,981

Source: 2010 and 2014 Canadian Community Health Survey (CCHS).
(.) represents missing observation

Table 8. Health utility index III scores for colorectal cancer by age group

	2010						2014					
	Both sexes		**Males**		**Females**		**Both sexes**		**Males**		**Females**	
Age group	No Cancer	Cancer	No Cancer	Cancer	No Cancer	Cancer	No Cancer	Cancer	No Cancer	Cancer	No Cancer	Cancer
35 to 44	0.90	0.84	0.90	0.97	0.90	0.82	0.89	0.93	0.90	(.)	0.88	0.92
	(0.17)	(0.10)	(0.17)	(0.00)	(0.17)	(0.09)	(0.18)	(0.13)	(0.17)	(.)	(0.19)	0.13
45 to 54	0.87	0.83	0.89	0.85	0.86	0.81	0.86	0.90	0.86	0.86	0.86	0.86
	(0.20)	(0.24)	(0.18)	(0.24)	(0.22)	(0.24)	(0.21)	(0.11)	(0.21)	(0.07)	(0.21)	0.12
55 to 64	0.85	0.74	0.86	0.75	0.85	0.73	0.84	0.76	0.84	0.78	0.84	0.74
	(0.21)	(0.24)	(0.21)	(0.25)	(0.21)	(0.23)	(0.22)	(0.41)	(0.22)	(0.44)	(0.21)	0.24
65 to 74	0.84	0.79	0.84	0.87	0.83	0.73	0.84	0.82	0.85	0.85	0.83	0.79
	(0.22)	(0.29)	(0.21)	(0.19)	(0.22)	(0.33)	(0.21)	(0.22)	(0.21)	(0.16)	(0.22)	0.26
75 to 84	0.79	0.74	0.82	0.82	0.77	0.69	0.79	0.71	0.80	0.75	0.78	0.65
	(0.25)	(0.23)	(0.23)	(0.17)	(0.27)	(0.25)	(0.25)	(0.27)	(0.25)	(0.28)	(0.26)	0.23
85+	0.69	0.68	0.68	0.70	0.69	0.66	0.70	0.68	0.72	0.70	0.68	0.66
	(0.31)	(0.30)	(0.31)	(0.27)	(0.30)	(0.30)	(0.30)	(0.33)	(0.29)	(0.32)	(0.31)	0.34
Weighted n	28,840,342	38,445	14,230,019	18,465	14,610,323	19,980	30,094,867	59,795	14,840,397	32,248	15,254,470	27,309

Source: 2010 and 2014 Canadian Community Health Survey (CCHS).
(.) represents missing observation

Table 9. Health utility index III scores for colorectal cancer population by income level

	2010						2014					
	Both sexes		Males		Females		Both sexes		Males		Females	
Income group	No Cancer	Cancer	No Cancer	Cancer	No Cancer	Cancer	No Cancer	Cancer	No Cancer	Cancer	No Cancer	Cancer
Less than 20k	0.82 (0.25)	0.72 (0.26)	0.82 (0.26)	0.73 (0.27)	0.82 (0.25)	0.72 (0.25)	0.80 (0.26)	0.42 (0.22)	0.79 (0.27)	0.32 (0.36)	0.80 (0.25)	0.58 (0.31)
$20,000 to $39.999k	0.87 (0.19)	0.74 (0.26)	0.87 (0.19)	0.80 (0.20)	0.87 (0.19)	0.71 (0.29)	0.85 (0.21)	0.85 (0.12)	0.85 (0.22)	0.88 (0.18)	0.85 (0.20)	0.80 (0.28)
$40,000 to $59,999k	0.90 (0.16)	0.79 (0.22)	0.90 (0.16)	0.81 (0.22)	0.90 (0.16)	0.70 (0.20)	0.89 (0.16)	0.87 (0.19)	0.89 (0.16)	0.88 (0.11)	0.90 (0.16)	0.86 (0.12)
$60,000 to $79,999	0.91 (0.14)	0.82 (0.25)	0.91 (0.14)	0.85 (0.07)	0.91 (0.13)	0.75 (0.49)	0.90 (0.14)	0.86 (0.38)	0.91 (0.14)	0.87 (0.16)	0.90 (0.15)	0.85 (0.20)
$80,000 or more	0.92 (0.13)	0.85 (0.07)	0.92 (0.14)	0.88 (0.03)	0.93 (0.12)	0.82 (0.07)	0.91 (0.15)	0.88 (0.17)	0.91 (0.14)	0.88 (0.06)	0.91 (0.15)	(.)
Weighted n	22,323,632	32,533	11,152,416	15,069	11,171,216	17,464	23,692,794	50,931	11,741,394	29,397	11,951,400	21,534

Source: 2010 and 2014 Canadian Community Health Survey (CCHS).
(.) represents missing observation

Table 10. Health utility index III scores for colorectal cancer population by education level

	2010						2014					
	Both sexes		**Males**		**Females**		**Both sexes**		**Males**		**Females**	
Education group	No Cancer	Cancer	No Cancer	Cancer	No Cancer	Cancer	No Cancer	Cancer	No Cancer	Cancer	No Cancer	Cancer
Less than secondary	0.84 (0.23)	0.69 (0.30)	0.85 (0.22)	0.76 (0.26)	0.82 (0.22)	0.65 (0.11)	0.82 (0.23)	0.58 (0.39)	0.83 (0.23)	0.52 (0.40)	0.82 (0.24)	0.69 (0.34)
Secondary grad	0.87 (0.19)	0.87 (0.21)	0.89 (0.17)	0.94 (0.09)	0.85 (0.19)	0.80 (0.00)	0.85 (0.22)	0.73 (0.24)	0.86 (0.21)	0.72 (0.30)	0.84 (0.22)	0.74 (0.22)
Other post-secondary	0.87 (0.20)	0.77 (0.25)	0.89 (0.19)	0.77 (0.25)	0.86 (0.20)	(.)	0.88 (0.17)	0.74 (0.25)	0.89 (0.17)	0.80 (0.15)	0.87 (0.18)	0.70 (0.28)
Post-secondary grad	0.90 (0.17)	0.76 (0.23)	0.90 (0.17)	0.80 (0.22)	0.89 (0.22)	0.73 (0.11)	0.88 (0.18)	0.86 (0.17)	0.89 (0.18)	0.89 (0.15)	0.88 (0.19)	0.84 (0.19)
Weighted n	27,845,017	37,373	13,717,664	17,643	14,127,353	19,730	29,604,449	59,344	14,574,539	32,035	15,029,910	27,309

Source: 2010 and 2014 Canadian Community Health Survey (CCHS).

(.) represents missing observation

Table 11. Cancer Population's HUI with multiple chronic conditions (2014 CCHS)

	No-Cancer		Cancer		Loss in HUI
# of Chronic Conditions	n	Mean HUI + SD	n	Mean HUI + SD	No-cancer - Cancer
1	144075	0.89 ± 0.15	2099	0.81 ± 0.22	-0.077*
2	159057	0.84 ± 0.18	5205	0.78 ± 0.22	-0.053
3	155758	0.74 ± 0.24	7660	0.65 ± 0.23	-0.093*
4	110243	0.68 ± 0.28	5378	0.62 ± 0.27	-0.059
5	78443	0.59 ± 0.28	5687	0.58 ± 0.26	-0.017
6	48968	0.52 ± 0.29	5652	0.42 ± 0.30	-0.095*
7	27431	0.39 ± 0.30	805	0.29 ± 0.23	-0.105*
8+	18669	0.31 ± 0.34	1130	0.18 ± 0.30	-0135*

Source: 2014 Canadian Community Health Survey (CCHS).

* Statistically significant [p<0.05]

Table 11. Health adjusted life expectancy for both sexes

	No Cancer					Cancer					Health adjusted life expectancy		
Age	**Probability of death**	**# surviving to age x**	**Person years lived at age x**	**Total numbers of years lived from age x**	**Life expectancy**	**Probability of death**	**# surviving to age x**	**Person years lived at age x**	**Total numbers of years lived form age x**	**Life expectancy**	**Health adjusted life expectancy (no-cancer)**	**Health adjusted life expectancy (cancer)**	**Loss of health expectancy**
X	q_x	l_x	L_x	T_x	e_x	q_x	l_x	L_x	T_x	e_x	$HALE_{nc}$	$HALE_c$	$HALE_{nc} - HALE_c$
1	0.0001	100,000	1,499,933	8,925,035	79.07	0.1536	100,000	1,384,768	4,001,030	40.01	71.12	(.)	(.)
15	0.0004	99,991	999,722	7,425,102	64.27	0.1971	84,636	762,943	2,616,262	30.91	56.81	21.21	35.60*
25	0.0006	99,953	999,242	6,525,380	54.85	0.1811	67,953	617,999	1,853,320	27.27	49.27	21.29	27.98*
35	0.0008	99,895	998,565	5,625,163	45.62	0.2351	55,647	491,061	1,235,321	22.20	40.73	16.64	24.09*
45	0.0015	99,818	997,429	4,724,929	36.45	0.3346	42,565	354,439	744,260	17.49	31.47	12.35	19.12*
55	0.0037	99,668	994,850	3,825,244	27.94	0.4416	28,323	220,687	389,820	13.76	23.47	10.42	13.04*
65	0.0095	99,302	988,288	2,927,243	20.11	0.5522	15,815	114,484	169,133	10.69	16.97	8.68	8.29*
75	0.0288	98,355	969,391	2,034,496	12.48	0.7283	7,082	45,030	54,649	7.72	9.91	5.67	4.24*
85	1.0000	95,523	477,614	1,158,839	5.00	1.0000	1,924	9,620	9,620	5.00	3.52	3.13	0.39*

Source: 2014 Canadian Community Health Survey (CCHS), Canadian Cancer Registry, and Vital Statistics
* Statistically significant [p<0.05]

Table 12. Health adjusted life expectancy for prostate cancer

	No Cancer					Prostate Cancer					Health adjusted life expectancy		
Age	Probability of death	# surviving to age x	Person years lived at age x	Total numbers of years lived from age x	Life expectancy	Probability of death	# surviving to age x	Person years lived at age x	Total numbers of years lived form age x	Life expectancy	Health adjusted life expectancy (no-cancer)	Health adjusted life expectancy (cancer)	Loss of health expectancy
X	q_x	l_x	L_x	T_x	e_x	q_x	l_x	L_x	T_x	e_x	$HALE_{nc}$	$HALE_c$	$HALE_{nc}$ - $HALE_c$
45	0.063	93,551	906,049	3,232,867	34.56	0.2207	100,000	889,640	1,910,598	19.11	29.95	15.99	13.96*
55	0.116	87,659	825,885	2,326,818	26.54	0.4304	77,928	611,580	1,020,958	13.10	22.38	10.74	11.63*
65	0.169	77,518	709,521	1,500,933	19.36	0.6403	44,388	301,776	409,379	9.22	16.49	7.38	9.11*
75	0.271	64,386	556,671	791,413	12.29	0.8261	15,967	93,719	107,603	6.74	9.90	5.05	4.84*
85	1.000	46,948	234,742	234,742	5.00	1.0000	2,777	13,883	13,883	5.00	3.65	3.27	0.39*

Source: 2014 Canadian Community Health Survey (CCHS), Canadian Cancer Registry, and Vital Statistics

* Statistically significant [p<0.05]

Table 13. Health adjusted life expectancy for breast cancer

	No Cancer					Breast Cancer					Health adjusted life expectancy		
Age	**Probability of death**	**# surviving to age x**	**Person years lived at age x**	**Total numbers of years lived from age x**	**Life expectancy**	**Probability of death**	**# surviving to age x**	**Person years lived at age x**	**Total numbers of years lived form age x**	**Life expectancy**	**Health adjusted life expectancy (no-cancer)**	**Health adjusted life expectancy (cancer)**	**Loss of health expectancy**
X	q_x	l_x	L_x	T_x	e_x	q_x	l_x	L_x	T_x	e_x	$HALE_{nc}$	$HALE_c$	$HALE_{nc}$ - $HALE_c$
35	0.013	98,268	976,512	4,703,462	47.86	0.1874	100,000	906,308	2,256,557	22.57	42.39	19.18	23.21*
45	0.028	97,034	956,790	3,726,950	38.41	0.2957	81,262	692,463	1,350,248	16.62	33.03	15.08	17.95*
55	0.058	94,324	915,996	2,770,160	29.37	0.5054	57,231	427,688	657,785	11.49	24.57	9.52	15.04*
65	0.102	88,875	843,386	1,854,165	20.86	0.7153	28,307	181,830	230,098	8.13	17.45	6.67	10.78*
75	0.233	79,802	704,894	1,010,779	12.67	0.9011	8,059	44,282	48,268	5.99	9.94	4.49	5.45*
85	1.000	61,177	305,885	305,885	5.00	1.0000	797	3,985	3,985	5.00	3.44	3.19	0.25*

Source: 2014 Canadian Community Health Survey (CCHS), Canadian Cancer Registry, and Vital Statistics

* Statistically significant [p<0.05]

Table 14. Health adjusted life expectancy for colorectal cancer

	No Cancer					Colon Cancer					Health adjusted life expectancy		
Age	Probability of death	# surviving to age x	Person years lived at age x	Total numbers of years lived from age x	Life expectancy	Probability of death	# surviving to age x	Person years lived at age x	Total numbers of years lived form age x	Life expectancy	Health adjusted life expectancy (no-cancer)	Health adjusted life expectancy (cancer)	Loss of health expectancy
x	q_x	l_x	L_x	T_x	e_x	q_x	l_x	L_x	T_x	e_x	$HALE_{nc}$	$HALE_c$	$HALE_{nc}$ - $HALE_c$
35	0.020	97,255	962,778	4,436,703	45.62	0.4351	100,000	782,457	1,447,065	14.47	40.73	13.44	27.28*
45	0.045	95,301	931,433	3,473,925	36.45	0.5346	56,491	413,911	664,608	11.76	31.47	10.62	20.84*
55	0.086	90,986	870,546	2,542,492	27.94	0.6416	26,291	178,564	250,697	9.54	23.47	5.32	18.15*
65	0.135	83,123	774,960	1,671,946	20.11	0.7522	9,422	58,785	72,132	7.66	16.97	6.31	10.66*
75	0.252	71,869	628,165	896,985	12.48	0.9283	2,335	12,511	13,362	5.72	9.91	4.04	5.87*
85	1.000	53,764	268,821	268,821	5.00	1.0000	167	837	862	3.15	3.52	2.47	1.05*

Source: 2014 Canadian Community Health Survey (CCHS), Canadian Cancer Registry, and Vital Statistics

* Statistically significant [p<0.05]

Appendix 1. Description of the datasets used

Canadian Cancer Registry

In 1992, the person-oriented Canadian Cancer Registry (CCR) evolved from the event-oriented National Cancer Incidence Reporting System established in 1969. The CCR is an administrative database. Beginning with cases diagnosed in 1992, cancer incidence data collected by provincial and territorial cancer registries (PTCRs) have been reported to the CCR, which is maintained by Statistics Canada.

The CCR is a collaboration between the 13 Canadian PTCRs and the Health Statistics Division of Statistics Canada, where the data are maintained. Ultimate authority and responsibility for the completeness and the quality of the data reside with the provinces and territories. The data that comes into the CCR describes both the individual with the cancer, and the characteristics of the cancer.

The CCR is a dynamic database of all Canadian residents, alive or dead, who have been diagnosed with cancer since 1992. The CCR is a patient-based system that records the type and number (incidence) of primary cancers diagnosed for each person until death. Subsequent primary cancers occurring for patients who are already in the database are linked to their existing patient information. The advantage of this system is that longitudinal data is available for each cancer patient. The patient data is regularly linked to mortality data (death clearance) to optimize the accuracy of date, cause, and place of death fields in the CCR and to identify potential primary cancers not currently registered in the CCR. Since patients' records remain active on the CCR until confirmation of their death, survival rates for the various forms of cancer can be calculated.

This linkage used the February 2014 CCR tabulation file. World Health Organization, International Classification of Diseases for Oncology, Third Edition (ICD-O-3) and the International Agency for Research on Cancer (IARC) rules for determining multiple primary types (source: International Agency for Research on Cancer, World Health Organization, International Association of Cancer Registries, and European Network of Cancer Registries. International Rules for Multiple Primary Cancers, ICD-O Third Edition, Internal Report No.2004/02. Lyon: International Agency for Research on Cancer, 2004) were used. Please see the footnotes for CANSIM table number 103-0550 for more information on the CCR.

Canadian Cancer Mortality Database and Canadian Vital Statistics

Variables measuring the incidence of mortality were obtained from the Canadian Mortality Database (CMDB). The CMDB contains data on deaths occurring in Canada from the year 1950 to the present. Deaths are reported annually by the provincial and territorial Vital Statistics Registries in Canada. This information is extracted from administrative files. Provincial and territorial Vital Statistics Acts (or equivalent legislation) make it mandatory for provinces and territories to register all live births, stillbirths, deaths and marriages occurring within their jurisdiction. These data are provided to Statistics Canada for further analysis.

Canadian Community Health Survey

The CCHS is a cross-sectional survey that collects information related to health status, health care utilization and health determinants for the Canadian population. The survey is offered in both official languages. It relies upon a large sample of respondents and is designed to provide reliable estimates at the health region level every 2 years. The CCHS produces an annual microdata file and a file combining two years of data. The CCHS collection years can also be combined by users to examine populations or rare characteristics.

The primary use of the CCHS data is for health surveillance and population health research. Federal and provincial departments of health and human resources, social service agencies, and other types of government agencies use the information collected from respondents to monitor, plan, implement and evaluate programs to improve the health of Canadians. Researchers from various fields use the information to conduct research to improve health. Non-profit health organizations and the media use the CCHS results to raise awareness about health, an issue of concern to all Canadians.

The survey began collecting data in 2001 and was repeated every two years until 2005. Starting in 2007, data for the Canadian Community Health Survey (CCHS) were collected annually instead of every two years. While a sample of approximately 130,000 respondents were interviewed during the reference periods of 2001, 2003 and 2005, the sample size was changed to 65,000 respondents each year starting in 2007.

In 2012, CCHS began work on a major redesign project that was completed and implemented for the 2015 cycle. The objectives of the redesign were to review the sampling methodology, adopt a new sample frame, modernize the content and review the target population. Consultations were held with federal, provincial and territorial share partners, health region authorities and academics.

As a result of the redesign, the 2015 CCHS has a new collection strategy, is drawing the sample from two different frames and has undergone major content revisions. With all these factors taken together, caution should be taken when comparing data from previous cycles to data released for the 2015 cycle onwards.

Appendix 2. HUI Classification System

Attribute	Level	Description
VISION	1	Able to see well enough to read ordinary newsprint and recognize a friend on the other side of the street, without glasses or contact lenses.
	2	Able to see well enough to read ordinary newsprint and recognize a friend on the other side of the street, but with glasses.
	3	Able to read ordinary newsprint with or without glasses but unable to recognize a friend on the other side of the street, even with glasses.
	4	Able to recognize a friend on the other side of the street with or without glasses but unable to read ordinary newsprint, even with glasses.
	5	Unable to read ordinary newsprint and unable to recognize a friend on the other side of the street, even with glasses.
	6	Unable to see at all.
HEARING	1	Able to hear what is said in a group conversation with at least three other people, without a hearing aid.
	2	Able to hear what is said in a conversation with one other person in a quiet room without a hearing aid, but requires a hearing aid to hear what is said in a group conversation with at least three other people.
	3	Able to hear what is said in a conversation with one other person in a quiet room with a hearing aid, and able to hear what is said in a group conversation with at least three other people, with a hearing aid.
	4	Able to hear what is said in a conversation with one other person in a quiet room, without a hearing aid, but unable to hear what is said in a group conversation with at least three other people even with a hearing aid.
	5	Able to hear what is said in a conversation with one other person in a quiet room with a hearing aid, but unable to hear what is said in a group conversation with at least three other people even with a hearing aid.
	6	Unable to hear at all.
SPEECH	1	Able to be understood completely when speaking with strangers or friends.
	2	Able to be understood partially when speaking with strangers but able to be understood completely when speaking with people who know me well.
	3	Able to be understood partially when speaking with strangers or people who know me well.
	4	Unable to be understood when speaking with strangers but able to be understood partially by people who know me well.
	5	Unable to be understood when speaking to other people (or unable to speak at all).
AMBULATION	1	Able to walk around the neighbourhood without difficulty, and without walking equipment.
	2	Able to walk around the neighbourhood with difficulty; but does not require walking equipment or the help of another person.

	3	Able to walk around the neighbourhood with walking equipment, but without the help of another person.
	4	Able to walk only short distances with walking equipment, and requires a wheelchair to get around the neighbourhood.
	5	Unable to walk alone, even with walking equipment. Able to walk short distances with the help of another person, and requires a wheelchair to get around the neighbourhood.
	6	Cannot walk at all.

DEXTERITY	1	Full use of two hands and ten fingers.
	2	Limitations in the use of hands or fingers, but does not require special tools or help of another person.
	3	Limitations in the use of hands or fingers, is independent with use of special tools (does not require the help of another person).
	4	Limitations in the use of hands or fingers, requires the help of another person for some tasks (not independent even with use of special tools).
	5	Limitations in use of hands or fingers, requires the help of another person for most tasks (not independent even with use of special tools).
	6	Limitations in use of hands or fingers, requires the help of another person for all tasks (not independent even with use of special tools).

EMOTION	1	Happy and interested in life.
	2	Somewhat happy.
	3	Somewhat unhappy.
	4	Very unhappy.
	5	So unhappy that life is not worthwhile.

COGNITION	1	Able to remember most things, think clearly and solve day to day problems.
	2	Able to remember most things, but have a little difficulty when trying to think and solve day to day problems.
	3	Somewhat forgetful, but able to think clearly and solve day to day problems.
	4	Somewhat forgetful, and have a little difficulty when trying to think or solve day to day problems.
	5	Very forgetful, and have great difficulty when trying to think or solve day to day problems.
	6	Unable to remember anything at all, and unable to think or solve day to day problems.

PAIN	1	Free of pain and discomfort.
	2	Mild to moderate pain that prevents no activities.
	3	Moderate pain that prevents a few activities.
	4	Moderate to severe pain that prevents some activities.
	5	Severe pain that prevents most activities.

Chapter 5. Conclusions

The three studies within this thesis (Chapters 2, 3, and 4) address questions of the economic burdens, loss of individual labour market earnings, and changes in health due to cancer for the Canadian population. Chapter 2 contributed to the literature by estimating the economic burdens of bladder cancer due to occupational exposure at the societal level. It provides insights into the potential gains to Canadian society through prevention. Chapter 3 draws on unique administrative datasets along with a methodology that provides a statistically robust estimation of a change in labour market earnings due to cancer diagnosis over a span of 5 years. It also provides insights into how different types of cancer can impact cancer survivors' labour market earnings trajectories. Using a combination of population surveys and linked administrative datasets, Chapter 4 provides an in-depth exploration of health profiles of individuals with cancer, and how these profiles differ by cancer types. The studies are ordered in a "top down" approach, with Chapter 2 taking a societal perspective to the impact of cancer diagnosis. Chapters 3 and 4 take a micro-level analysis of the impact of cancer on labour market earnings and health, respectively. This final chapter summarizes the principal findings of the three studies, discusses the contribution of the thesis to the literature on the economics of cancer, reviews the strengths and limitations of the studies, and ends with some suggestions for health economics research going forward, in the area of cancer.

Principal findings

In Chapter 2, an economic costing approach allowed for the measurement of the lifetime economic burden of cancer diagnosis for five stakeholders groups—individual, family and community, employer, system and public sector, and society—in this study. The findings also included detailed itemized costs across three broad categories—direct, indirect, and intangible—

and found substantial economic burdens associated with occupational cancer. In terms of intangible costs, our results corroborated with the findings of Tompa et al., (2017) and Modifi et al., (2018) and fell between that of lung cancer and mesothelioma. Notably, the key contribution was highlighted by the finding that the impact of cancer was not isolated to an individual, but that there was a spillover effect on family members and friends in the forms of informal care costs, friction costs and loss of productivity for employers, and loss of economic output for society.

The study findings are relevant to Canadian policymakers and those who are involved in work-related disease, as the economic costs of cancer due to occupational exposures could be avoided by implementing preventative measures (Kang et al., 2003, Max et al., 2004). Policymakers can potentially take the findings as evidence of the value of reducing exposures to or eliminating carcinogens in the workplaces. Ultimately, Chapter 2 contributes to the literature by providing the magnitude of the economic burdens of cancer, indicating that in addition to the burden faced by cancer patients, there is a spillover effect for caregivers, employers, and society.

In Chapter 3, the results indicated that cancer survivors suffer a statistically and economically significant labour market earnings loss over the span of the 5-year follow-up period. The cancer survivors' earnings followed a "U-shaped" trajectory. At $t=1$, or one year after the cancer diagnosis, cancer survivors suffered the largest loss of labour market earnings. At $t=2$ or 2 years after the diagnosis, the cancer survivors' earnings showed a sign of recovery, and the earnings differences between individuals with cancer and individuals without cancer started to converge over the next 3 years. Across different age groups, cancer survivors in the age group of 25 to 54, the active labour market group, suffered the largest loss of labour market earnings at $t=1$, 1 year after the diagnosis. We also found a heterogeneous relationship between

cancer types and the loss of labour market earnings, where the magnitude of labour market earnings loss is closely in alignment with the severity of the cancer type.

Chapter 3 expanded the understanding of heterogeneous effects of different cancer types, as few studies (Mathews et al., 2009; Moran et al., 2011; Syse et al., 2008) in the literature have looked at the association of labour market earnings and different cancer types independently, and only one in Canada (Jeon, 2017) has controlled for the severity of cancer. To our knowledge, our study is the first attempt at estimating the loss of labour market earnings by 12 different cancer types across two age groups (less than 55 and over 55 years old). Particularly, we found a persistent loss of labour market earnings among individuals with more severe cancer types (i.e., pancreatic cancer), whereas individuals with less severe cancer types (i.e., skin cancer) earned higher labour market earnings compared to individuals without cancer at t=4.

In Chapter 4, linked-administrative datasets allowed us to employ a life table methodology to estimate the health profile of individuals with cancer in Canada. The individuals with cancer had lower health compared to individuals without cancer based on three commonly used health indicators: life expectancy, health utility index, and health adjusted life years. Looking across different cancer types, we found a relationship between the severity of cancer types and health, where individuals with more severe cancer types reported lower health. The results from Chapter 4 reaffirm the idea that no two cancers are the same, as we found heterogonous effects of cancer types on three different health indicators. Compare to other chronic diseases, such as diabetes and hypertension, individuals with cancer had the largest loss across all three health indicators at age 25.

Study contributions

Together, all three original studies presented in this thesis provide insight into the impact of cancer on multiple outcomes, particularly the societal economic burden, annual labour market earnings, and the health of individuals with cancer in Canada. The societal economic burden of cancer diagnosis was presented in Chapter 2, and the heterogeneous and temporal effects of cancer types on annual labour market earnings was presented in Chapter 3. In Chapter 4, we presented the health of the individuals with cancer across three different cancer types using three commonly used health indicators.

Substantive contributions

Chapters 2 and 3 contribute to literature on the economic burden of cancer. In Chapter 2, findings indicate that there is a substantial economic burden associated with cancer diagnosis, even in a society with a universal healthcare system: intangible costs take the largest share of the costs, followed by indirect and direct costs. Within the indirect cost category, loss of income due to morbidity and mortality comprise the largest component of the costs.

Using uniquely linked administrative datasets in Chapter 3 we identified newly diagnosed cancer starting in the year 1992, while controlling for cancer types, sociodemographic characteristics, and prior labour market attachment before the diagnosis. We were able to isolate the impact of cancer on labour market earnings over a span of 5 years after the initial diagnosis by matching the individuals without cancer to the individuals with cancer. The results of Chapter 3 contribute to the literature by providing estimates of the lasting and heterogeneous effects of cancer on labour market earnings.

Chapter 4's findings contribute to better understanding the health profiles of the individuals with cancer based on three commonly used health indicators looking at mortality (i.e., life expectancy), health utilities (i.e., Health Utility Index), and health-adjusted life expectancy. Additionally, the findings demonstrate how health differs by cancer types and sociodemographic characteristics. Ultimately, Chapter 4 provides a health profile of individuals with cancer based on three different health indicators.

Methodological contribution

All studies (Chapter 2, 3, and 4) took methodological approaches that have been proven to be reliable and robust to address the questions proposed. Chapter 2 utilized an economic costing methodology (Tompa et al., 2017) to measure the economic burdens of a bladder cancer due to occupational exposure. Combined with the Markov method (Briggs and Schulpher, 1989), we estimated the lifetime costs of a cancer diagnosis by estimating the individual costing item across three broad categories: direct, indirect, and intangible. Chapter 3 used the Mahalanobis' distance and propensity score matching method (Leuven and Sianesi, 2003) combined with a difference-in-difference regression to identify individuals without cancer that were similar to the individuals with cancer on observable sociodemographic characteristics, and to estimate the impact of cancer on nominal ($) and percentage (%) change in annual labour market earnings respectively. Finally, Chapter 4 applied a life table methodology (Statistics Canada 2018) to estimate life expectancy, the bootstrapping method to estimate the population variance of health utility index III, and a modified Sullivan (1971) method to estimate health-adjusted life expectancy for the individuals with cancer in Canada.

Theoretical contribution

The Cambridge English Dictionary defines a theory as:

> 1. A formal statement of the rules on which a subject of study is based or of an idea that is suggested to explain a fact or event or, more generally, an opinion or explanation;
>
> 2. Something suggested as a reasonable explanation for facts, a condition, or an event.

By applying the second definition, the findings of Chapters 3 and 4 contribute to the theory and conceptualization of how and to what magnitude different cancer types can have on labour market earnings and health of individuals respectively. The Chapter 3's findings are consistent with recent literature that investigated the impact of different cancer types on earnings (Benth et al., 2014, Moran et al., 2011), and thus contribute to an on-going effort to understand the heterogeneous effects of cancer types on labour market earnings. Chapter 2 expands the scope of items considered for economic costing analysis, first developed by Tompa et al (2017), by including the intangible cost category, thereby planting the first seed of expansion and dialogue within the economic costing framework.

Strengths and limitations

Despite some important theoretical, methodological, and substantive contributions of this thesis, several limitations must be acknowledged relating to data availability and the short follow-up period of the studies. The use of population surveys and linked administrative datasets that are representative of the individuals with cancer in Canada in Chapters 3 and 4 is one of the strengths of this thesis. Additionally, drawing a clear distinction between cancer types provides rich evidence on the heterogeneous effects on labour market earnings (Chapter 3) and health (Chapter 4), thereby reaffirming that no two cancers are the same.

Chapter 2 makes use of various rich population-level micro- and macro-data sources to estimate the economic burden of newly diagnosed cases of occupational cancer in Canada. The study provides the results by sex, age bracket, and the stage of cancer to provide sub-strata details. Also, the study uses detailed costing methods and accounts for all resources in direct and indirect cost categories, as well as the value of losses in health-related quality of life, something that previously published studies have failed to capture. Our study was also more comprehensive in our estimates of indirect costs, including both employers' costs and productivity losses associated with morbidity and premature mortality due to cancer.

There were data limitations that required us to use less than optimal estimates from secondary data sources, which may have resulted in a less precise estimation of the economic burden. Additionally, assigning an appropriate monetary value to QALYs was a challenge, as the value used in different contexts and countries can vary dramatically (e.g., the health technology assessment field in Canada has used $50,000 (Hirth et al., 2000) for decades, whereas in the United Kingdom uses £75,000 GBP (Appleby, Devlin and Parkin., 2007). To address this uncertainty, we carried out a probabilistic sensitivity analysis using a maximum and minimum value from the aforementioned studies around the $50,000/QALY value used in our core analysis. The economic burden of bladder cancer due to occupational exposure was estimated marginally, relatively to Canadians in the same age group and sex across all costing items except health care costs. This would result in the overestimation of direct costs but would not alter the overall economic burden as the direct costs only account for 2% of the costs.

Chapter 3 employed statistical methods to produce reliable and robust estimates describing cancer survivors' labour market earnings using linked administrative datasets from 1991 to 2013. Due to the availability of a unique dataset for the first time for individuals with

cancer in Canada, we were able to identify individuals without cancer with similar characteristics as the cancer survivors, and therefore isolate the impact of cancer diagnosis on annual labour market earnings over a follow-up period of 5 years. In addition to that, cancer type-specific estimation was carried out in order to differentiate the impact of cancer types on labour market earnings across the active age group (25–54 years old) and the less active age group (55+).

In terms of limitations, something we realized after the completion of the study is that a longer follow-up period was necessary, as many of the cancer survivors had a persistent loss of labour market earnings even 5 years after the initial cancer diagnosis. Additionally, a lack of observation on the stages of cancer prevented us from providing a more accurate picture of the impact of a cancer diagnosis.

The strengths of Chapter 4 are twofold. First, the study provides a step-by-step methodology using a modified Sullivan method to estimate health-adjusted life expectancy by cancer types and age groups. Secondly, the study provides a health profile of individuals with cancer and by cancer type in one paper using three health indicators, as other studies have examined the health among individuals with cancer independently.

Chapter 4's limitations share many similarities with Chapter 3, in that there does not exist any cancer staging information for the individuals with cancer, and this prevented us from distinguishing the health of the individuals with cancer by severity of cancer using the staging information. Other limitations include the dataset's cross-sectional nature, reliance on self-report, limitations of the cancer types information other than three types: breast, colorectal, and prostate.

Final thoughts

This thesis brings to light some important areas for future research and extensions. Considering that Chapter 3 of our study found a persistent loss of labour market earnings among cancer survivors, even after the 5-year follow-up period, one direction for future studies is to create a panel-level dataset and follow the cancer survivors for an extended period of time. At this point, it is difficult to suggest an optimal follow-up period but the studies (Paalman et al., 2016, Hodgkinson et al., 2007) suggest that a 10-year a follow-up period might be a good place to start. Considering the labour market earnings and health outcomes, this thesis found that the individuals with cancer are negatively impacted by cancer, but we were not able to discern the differences within cancer types using the staging information. Using the linked datasets in Chapters 3 and 4, we noticed that only about 10% of the records report any cancer staging information. If the granular-level cancer-related data collection can be enhanced, this would enable us and other researchers to provide improved estimates across cancer types and stages of cancer. Similarly, Chapter 2 investigated the economic burden of bladder cancer due to occupational exposure. This area of inquiry might be broadened to include all work-related cancer types and their economic burden to highlight the magnitude of cost of workplace carcinogens. This would undoubtedly start a dialogue on the merits of prevention strategies.

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