The Dollars and Cents of Driving and Cycling: Calculating the Full Costs of Transportation in Calgary, Canada

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Abstract: Many cities across the globe are working to facilitate cycling as a sustainable transportation mode through changes to public policy and investments in infrastructure. Examining the costs and benefits of both driving and cycling using the cost benefit analysis (CBA) framework developed in Copenhagen provides an opportunity to identify private and social costs associated with these modes of transport with respect to environmental, social, and economic impacts. This paper outlines the methods used to calculate the per-kilometre costs of driving and cycling in Calgary, Canada, utilizing real-world data and methods from Canadian and global best-practice with the Copenhagen CBA framework as a guide. Transportation costs were calculated for travel time, vehicle ownership, health, collisions, air pollution, climate change, noise, roadway degradation, congestion, and winter maintenance for both driving and cycling. When the costs borne by both individuals and society are calculated for Calgary (in 2015 Canadian dollars) driving costs $0.83 per kilometre and cycling costs $0.08 per kilometre. When the social costs of transport are isolated, the cost of driving one kilometre is $0.10, while cycling one kilometre generates a net social benefit of $0.35. The results of this research show that the Copenhagen CBA framework can be applied in jurisdictions outside Denmark to calculate environmental, social, and economic costs of driving and cycling.

Keywords: Sustainable Development, Cost-Benefit Analysis, Cycling, Driving, Internalization of External Costs

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Summary: Cities all over the world invest large sums of money to build and operate sustainable transportation networks to move people and goods through the urban environment. Deciding where to direct capital investment and maintenance funding for transportation while balancing constrained budgets is a significant challenge for modern cities.

Increasing priority is being placed on providing transportation options for citizens that do not rely exclusively on the personal automobile. By investing in active transportation such as cycling or walking in addition to transit and driving, it is possible to make urban transportation networks more sustainable and resilient while at the same time reducing air pollution, congestion, noise, and increasing physical activity and the health benefits generated by active transportation.

Copenhagen is one of the most bicycle friendly cities in the world, to help direct investments in bicycle infrastructure there a cost-benefit analysis (CBA) framework was developed for assessing the environmental, social, and economic impacts of both automobile and bicycle transport.

This research project explored the applicability of the Copenhagen framework in a Canadian city: Calgary. It was shown to be possible to use the Copenhagen CBA framework as a guide in calculating the costs of automobile and bicycle transportation using real-world transportation data from Calgary in conjunction with methods identified in Canadian and global best-practice. It was also shown to be possible to modify the Copenhagen CBA framework to include additional costs of transport relevant in Calgary, namely winter maintenance.

The results of this research indicate that on average, driving costs $0.87 per kilometre, while cycling costs $0.08 per kilometre. When considering just the social impacts, driving costs $0.10 per kilometre while for every kilometre travelled by bicycle generates a net benefit to society of $0.35.

Keywords: Sustainable Development, Cost-Benefit Analysis, Cycling, Driving, Internalization of External Costs

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1. Introduction

Transportation is a key consideration for cities as urban populations increase the world over. Building and maintaining a network of transportation infrastructure for people to move through urban space is a significant challenge in modern cities. Providing a range of transportation options such as cycling, walking, and public transport for citizens in addition to travel by personal automobile is becoming a higher priority for many cities and is an important component of sustainable urban development.

Active transportation, such as cycling, has the capacity to address several transportation, health, and environmental concerns concurrently. Increasing levels of cycling in a city can help to reduce congestion, traffic noise, and demand on public transport systems while improving health among citizens through physical activity, as well as reducing air pollution and greenhouse gas emissions associated with automobile travel (Litman, 2014).

While the benefits of cycling for transportation are many, transportation budgets are generally constrained and investments in cycling infrastructure must be considered within the larger context of the transportation network as a whole. In order for cycling to become a viable transportation option, policy, urban planning, development, and infrastructure investment need to be in alignment. Calculating the private and social costs of cycling and comparing them to the costs of driving an automobile may help to support policies, initiatives, and projects aimed at increasing cycling transportation by providing a direct valuation of the benefits and costs of cycling.

Copenhagen, which aims to be the most bicycle friendly city in the world (City of Copenhagen, 2014) has developed a cost benefit analysis (CBA) framework for assessing investments in cycling infrastructure (COWI and City of Copenhagen, 2009). CBA can be used to examine the advantages or disadvantages of a policy or project based on the monetization of its associated impacts, with the resulting net cost or benefit providing guidance to decision makers (Hanley & Spash, 1993). A key component of the Copenhagen CBA framework is the quantification of costs of driving and cycling per kilometre travelled across thirteen impact categories and specifically identifying the private costs borne by the user as well as the social costs borne by society at large (COWI and City of Copenhagen, 2009).

The objective of this research project was to determine if the Copenhagen CBA framework could be applied to quantify the costs of driving and cycling in Calgary, Canada. By attempting to apply the Copenhagen CBA framework in Calgary this research was able to answer the following questions:

Is it possible to calculate the unit costs of driving and cycling for the impact categories identified in the Copenhagen CBA framework using real-world data from Calgary with methods identified in research from Canadian and global best practice?

Can the Copenhagen CBA framework be modified to suit local conditions in Calgary?

This paper describes the process developed to quantify the per kilometre costs of driving and cycling in Calgary based on the Copenhagen CBA framework. The methods used to calculate the costs of driving and cycling are provided and the results are discussed in comparison to the costs identified in the Copenhagen CBA framework.

2. Background

The transportation of people and goods generates a range of impacts, including land requirements for transportation rights-of-way, water pollution from road surface runoff, visual impacts of transportation infrastructure, production of air pollution including greenhouse gases, roadway congestion, vehicle collisions, traffic noise, as well as the on-going costs of infrastructure maintenance (Litman, 2014; Transport Canada, 2008).

As urban populations grow around the globe, cities are increasingly aware of the need to
develop sustainably and consider the environmental and social implications of growth in addition to the economic effects, the so-called triple bottom line (TBL) approach (The City of Calgary, 2011b). Figure 1 illustrates a model of “strong sustainability” where the economy is understood as a component of society, and that both elements operate within the larger context of the environment as a whole (Parliamentary Commissioner for the Environment, 2002).

Examine the impacts of transportation in a holistic way is complex, and while policy may indicate that the environmental, social, and economic aspects of transportation must be considered, it is no easy task to comprehensively examine all associated impacts across these three areas. Transportation networks connect people to schools, places of work, recreation areas, and all the amenities to be found in the urban environment. By supporting active modes of transport such as cycling, which requires less energy and is more financially accessible to more people, cities are able to reduce reliance on personal automobile travel and utilize infrastructure that costs less to build than roadways, such as bicycle paths (The City of Calgary, 2009a). In short, active transportation is more sustainable; figure 2 illustrates the relative sustainability of various modes of transport identified in the Calgary Transportation Plan (2009a).

In order to guide decision making related to investments in transportation while taking into account environmental, social, and economic impacts, certain economic tools, such as CBA, are commonly used to explicitly state the potential impacts of proposed policies or projects (Hanley & Spash, 1993). The following section will explore how the TBL approach can be supported by CBA. Additionally, background information will be provided on both Copenhagen and Calgary, with a brief examination of cycling in Calgary and a summary of the existing literature and research used in the quantification of the costs of driving and cycling in Calgary.

Figure 1: A model of “strong sustainability” (Parliamentary Commissioner for the Environment, 2002).

Figure 2: Relative sustainability of various transportation modes (The City of Calgary, 2009a).

2.1. Triple Bottom Line and Cost-Benefit Analysis

The TBL approach to analysing transportation policy and projects allows for an examination of not only the economic impacts of transportation, but environmental and social impacts as well. One challenge associated with the TBL approach is that it does not necessarily provide a way to compare environmental and social impacts in the same way that economic impacts are normally assessed.

CBA is a tool that can be used to examine not only the direct economic impacts of a project, such as capital construction and maintenance costs, but also external environmental and social impacts (Hanley & Spash, 1993).

CBA involves selection of the potential impacts of a policy or project across a selected time horizon, quantification of the chosen impacts, monetary valuation of the impacts, and a summary of net benefits and costs of the impacts examined (Hanley & Spash, 1993).
Inclusion of external costs, often environmental and social, in the CBA can to some degree internalize these costs for a particular policy or project (Bithas, 2011). The selection of impacts to examine in the CBA, and the valuation of external costs is influenced by the ideological orientation of the actors involved in the analysis and subsequent decision making process (Söderbaum, 2015).

There are shortcomings with CBA as a decision making tool, such as the difficulty in identifying every impact associated with a project or policy across time horizons spanning multiple generations, as well as assigning monetary value to the impacts, particularly considering the principles of value incommensurability and fairness (Bithas, 2011; Gössling & Choi, 2015). Additionally, there are risks that the CBA process is overly reductionist (valuing impacts only in economic terms), that it can lack transparency and public participation, that it may fail to adequately represent non-priced impacts or double count potential impacts, and that it may present incomplete information to decision makers (Annema et al., 2007). Despite these limitations, CBA is a commonly employed and traditionally accepted economic tool in decision making, particularly for investments in transportation infrastructure. By recognizing that CBA is not a comprehensive solution to understanding a project’s impacts (Hanley & Spash, 1993) but a component in the decision making process which needs to be in alignment with stated policy and developed with input from a range of stakeholders and the public, it is possible to mitigate some of the risks associated with the traditional CBA (Söderbaum, 2015).

The CBA framework developed in Copenhagen includes a wide range of impacts related to automobile and bicycle transport, including vehicle operating costs, travel time costs, accident costs, pollution and externalities, recreational value, health benefits, safety, discomfort, branding, and system benefits (COWI and City of Copenhagen, 2009). One of the strengths of the Copenhagen CBA framework is that political consensus was reached on which categories should be included, a unique achievement to Copenhagen (Gössling & Choi, 2015). Quantification of the impacts included in the Copenhagen CBA framework was developed using methods such as contingent valuation, hedonic pricing, travel cost method, avoided social costs, health costs, and shadow pricing (COWI and City of Copenhagen, 2009). These unit costs are updated annually in the Transportøkonomiske Enhedspriser developed by the Danish Transport Ministry (DTU Transport, COWI, 2013).

2.2. Calgary and Copenhagen

Copenhagen is a long-established coastal city in northern Europe with relatively flat topography and Calgary is a relatively new city on the eastern edge of the foothills of the Rocky Mountains. These two cities represent very different urban forms and transportation networks: a compact, high-density city, with a robust network of cycling facilities (City of Copenhagen, 2009), and a lower density urban form prioritizing the efficient movement of automobiles (The City of Calgary, 2009a).

While these two cities are structurally and historically very different, they have similar populations (1.2 million) (Statistics Denmark, 2015; The City of Calgary, 2015a) and share a vision of being bicycle friendly (City of Copenhagen, 2014; The City of Calgary, 2011a). Copenhagen has, since the 1970s, been investing heavily in bicycle infrastructure and the current cycling statistics reflect this (City of Copenhagen, 2009). The cycling mode share in Copenhagen for commuting trips to places of work and education is 45%, with 1.34 million kilometres travelled by bicycle every weekday, and 3 out of 4 people who cycle doing so year-round (The City of Copenhagen, 2015). In Calgary, the cycling mode share for commuting to work is 1.4%, with 250,000 kilometres travelled by bicycle on an average autumn weekday, and 1 out of 3 people who cycle doing so year-round (Martin, 2016; The City of Calgary, 2013a; The City of Calgary, 2014b).

The significant variance in cycling mode share between Copenhagen and Calgary reflects their historical, structural, and cultural differences. It is because of these differences however, that...
applying the Copenhagen CBA framework to quantify the costs of driving and cycling in Calgary serves as an illustrative test case for the applicability of the framework in other jurisdictions.

2.3. Calgary and Cycling

Cycling in Calgary for transport and recreation has been supported by municipal government plans and policies for many decades but the past fifteen years have seen an increasing emphasis on cycling as a viable transportation option in the city.

The Calgary Pathway & Bikeway Plan (The City of Calgary, 2001) provided a set of guiding principles on the planning, development, and maintenance of the network of on-street bicycle facilities (such as bike lanes) and off-street bicycle infrastructure (such as multi-use pathways) throughout the city for transportation and recreation. The plan also recognized the health benefits of active transportation and its contribution to community vitality. A city wide network of on-street and off-street bicycle facilities was also included in the plan, to guide urban planning efforts and investments in pathways and bikeways infrastructure, and to ensure that large transportation infrastructure projects provide connectivity for cyclists and pedestrians (The City of Calgary, 2001).

The Bicycle Policy and Needs Report (The City of Calgary, 2008) reiterated that cycling, as a meaningful transportation choice for social and economic interaction, was to be supported by a safe, well designed, connected, convenient, comfortable and well maintained network of bicycle routes and facilities.

In 2009 the Calgary Transportation Plan and the Municipal Development Plan tied transportation and land-use to long-term sustainability, with priority placed on providing safe, attractive, and convenient transportation infrastructure supporting mobility options such as walking and cycling in all transportation planning projects (The City of Calgary, 2009a; The City of Calgary, 2009b).

The Cycling Strategy, passed in 2011, outlined Calgary’s vision to become a premier cycling city in North America, focusing on making the city more bicycle-friendly through the implementation of bicycle infrastructure, increasing the standards for operating and maintenance of bicycle facilities, as well as pursuing education for, and promotion of, safe cycling (The City of Calgary, 2011a). Funding for cycling infrastructure and the other initiatives identified in the Cycling Strategy was allocated in the 2012-2016 capital budget for Transportation, with 1.2% of the total budget supporting the strategy ($22.7 million of $2.1 billion) (The City of Calgary, 2013b). These funds were dedicated to capital expenses related to the Cycling Strategy; pathway projects, multi-modal projects, and administrative costs are not included in this amount.

An update to the Triple Bottom Line Policy Framework in 2011 formalized the requirement for municipal projects to include economic, social, and environmental considerations to ensure alignment with the “imagineCalgary” 100-year vision for community sustainability (The City of Calgary, 2011b).

Most recently, in 2014, the Complete Streets Policy was passed, revising street design standards to accommodate all street users including cyclists, pedestrians, and transit users (The City of Calgary, 2014a).

While the adopted policies and capital funding allocation in Calgary support cycling transportation, there remains a gap between the soft policy ambitions and the quantification of the effects transportation projects and policies. The following section identifies the results of a literature search conducted to find published research and information related to the external impacts of transportation in Canada.

2.4. Transportation Cost Research

A great deal of research exists regarding calculating the external costs of automobile transportation, far less research has been done to quantify the external costs of bicycle transportation. As cities prioritize cycling as a transportation option however, it is becoming
more important to examine the impacts of cycling projects in greater detail using similar methods to those employed for automobile transportation projects. Given the focus of this research project on the calculation of the costs of driving and cycling in Calgary, this section will only identify sources of information relevant to the generation of unit costs of the impacts of transportation identified in the Copenhagen CBA framework.

Research by Gössling and Choi (2015) provided a summary of the Copenhagen CBA framework for analysing cycling projects, with a review of current research and discussion of CBA as a general tool for project analysis. Gössling and Choi’s 2015 article on the Copenhagen CBA framework led to an exploration of published European research on the methodologies developed for analysing and calculating the external costs of transportation, and provided direction for further research into Canadian methodologies and cost calculations.

Examining the Copenhagen CBA framework itself was critical in the research for this project as it provided information on how the unit costs were developed for driving and cycling in Copenhagen, the allocation of private and social costs for transport, and information on how these unit costs could be used in the analysis of bicycle transportation projects (COWI and City of Copenhagen, 2009). While the summary of the Copenhagen CBA framework provided in English was extremely valuable for this research, the full version translated from Danish may have provided additional insight. The list of transportation unit costs developed by the Danish Transport Ministry (DTU Transport, COWI, 2013) was another important resource in this research as it outlined in great detail the various external costs associated with automobile transport as well as for travel by bicycle.

Two reports published by the European Commission, in 2008 and updated in 2014, outlined current European best practice for calculating external costs of automobile transport (Maibach et al., 2008; Korzhenevych et al., 2014). These reports explain in depth the various types of external costs that are generated from automobile transportation, such as congestion costs, health impacts of air pollution, the costs of automobile collisions/accidents, climate change impacts from greenhouse gas emissions, and noise generated by automobiles. These reports also provided background on the economic theory behind how these calculations are developed and include tables of cost values for all European nations with summaries of existing research from several countries within the EU. These reports provided theoretical and methodological information on calculating external costs of transportation. This information helped to direct research into the types of information required from Canadian sources to quantify the costs of driving and cycling in Calgary while ensuring alignment with European best practice.

In the area of the health impacts of active transportation, the European Commission reports identified key research done by the World Health Organization (WHO) on reductions in mortality resulting from the physical activity associated with cycling and walking. The WHO research includes a web-based tool for calculating the effects of active transportation on mortality, the Health Economic Assessment Tool (HEAT) (WHO, 2014), which was used in this research project and is described further in the method section 3.3.3.

In order to determine unit costs for transportation-related impacts included in the Copenhagen CBA for Calgary, it was necessary to search for published research from Canada. Two reports by Transport Canada, the federal body responsible for transportation policies and programs in Canada were particularly relevant and provided a range of cost information and calculation methods. Similar to the European Commission reports, the Transport Canada research included economic theory and methods for calculating external costs of transport, such as the costs of greenhouse gas emissions, the health impacts of air pollution from automobiles, the value of a statistical human life (VSL), and the costs of urban congestion (Transport Canada, 2006; Transport Canada,
Research published by the Victoria Transport Policy Institute (VTPI) collected information on a range of costs related to transport, such as health benefits of active transportation, and the cost of noise generated by automobile traffic (Littman & Doherty, 2011). Regarding the health impacts of active transportation, the VTPI research presented information from several sources, with reports for the New Zealand Transport Agency identifying suitable cost data and allocation between private and social costs.

While it was not always possible to rely on Canadian research and methods, in the development of the cost calculations of external impacts related to transportation for this project all attempts were made to utilize Canadian information in combination with global and European best practice. The results of this research project represent an attempt to explore the potential to reverse engineer the unit costs provided by the Danish Transport Ministry by employing European and Canadian methods with transportation data from Calgary.

The following section of this paper explains the process of using the Copenhagen CBA framework to quantify the various impacts related to driving and cycling in Calgary, using actual and modelled traffic data and research available from Canadian sources where suitable. A full list of all research and data used can be found in Appendix A, table 4.

3. Method

The primary purpose of this research was to calculate the costs of driving and cycling in Calgary using the Copenhagen CBA framework as a guide, as it examines a broad range of impacts related to transportation for both modes of transport which were agreed upon at the political level and which represent global best-practice with regard to calculating the full costs of automobile and bicycle transport (Gössling & Choi, 2015).

The Copenhagen CBA framework is discussed in further detail in section 3.1, with the adaptation of the framework to the Calgary context explored in section 3.2. Following this, detailed information is provided on the calculation of unit costs for each of the impact categories in Calgary for both driving and cycling. The complete results of all cost calculations are summarised in table 1, with a list of all data sources and research used for each calculation provided in Appendix A, table 4.

It is relevant to note that a CBA for an actual transportation project in Calgary is not a part of this research, though the unit costs calculated in this research could be used to do so in future by following the steps identified in the Copenhagen CBA framework.

3.1. Copenhagen’s Cost-Benefit Analysis Framework

The CBA framework developed in Copenhagen includes thirteen categories of impacts related to driving and cycling: travel time costs, vehicle operating costs, prolonged life, health, accidents, perceived safety, discomfort, branding and tourism, air pollution, climate change, noise, road deterioration, and congestion (COWI and City of Copenhagen, 2009).

Each of these categories may include a combination of private costs, borne by the driver or cyclist (such as fuel purchase or time spent travelling), and social costs, borne by society at large (such as the external costs of air pollution) (COWI and City of Copenhagen, 2009).

Two of the cost categories in the Copenhagen CBA framework do not have defined values: perceived safety and discomfort. As described in summary of the CBA framework, these are difficult to quantify at this time, though it may be possible to include them in the future as further research is conducted (COWI and City of Copenhagen, 2009).

When the costs of driving and cycling were quantified in the Copenhagen CBA framework, it was found that driving costs considerably more, per kilometre travelled, than cycling (COWI and City of Copenhagen, 2009). When converted into 2015 Canadian dollars, the
average cost of driving one kilometre in Copenhagen is $0.87, with cycling one kilometre costing $0.14 (COWI and City of Copenhagen, 2009). A complete breakdown of all the costs of driving and cycling in Copenhagen, both personal costs and social costs, can be found in Table 2.

In a full economic cost-benefit analysis, the unit prices for each cost category would be used to estimate the total economic impact of a proposed project or initiative based on projected changes to traffic volumes (COWI and City of Copenhagen, 2009). For this project, the CBA framework will be used to calculate unit costs for Calgary, but a full cost-benefit analysis for a specific project will not be completed.

3.2. Applying Copenhagen’s CBA Framework in Calgary

In order to translate the Copenhagen CBA framework to Calgary, a slight modification of the cost categories was required. Additionally, traffic statistics, traffic modelling data, and budgetary information was needed to calculate the unit costs for this project. Explanations for changes to the cost categories used in this analysis and a description of the types of data used to quantify the costs of driving are included below.

3.2.1. Cost Categories

The Copenhagen CBA framework includes two categories for which no unit price is included: perceived safety and discomfort (COWI and City of Copenhagen, 2009). As no monetary values for these two cost categories were included in the Copenhagen CBA framework, they were excluded from the calculations for Calgary. A third category, branding/tourism, was also excluded, for while Copenhagen markets the city as “the most bicycle friendly city in the world” (City of Copenhagen, 2014), cycling in Calgary as a tourist activity is less prevalent and obtaining data to quantify the branding/tourism costs or benefits for cycling is beyond the scope of this project.

An additional cost category was included for this project that is perhaps more relevant in Calgary than in Copenhagen: winter maintenance. Keeping on-street and off-street bicycle facilities clear of snow throughout the winter requires significant municipal resources and, given this annual maintenance cost, a winter maintenance category was included in this project to reflect this additional expense.

3.2.2. Data Requirements

In order to quantify the costs of driving and cycling on a per kilometre basis, transportation and other types of data were required. Transportation information was provided by the municipal government of Calgary (The City of Calgary) and included traffic counts, transport modal split data, demographic information, and budgetary data. Information about certain bicycle and automobile travel patterns and traffic volumes, as well as pollution emissions, were generated by traffic models used by the Transportation Planning business unit.

Specific data required to calculate transport costs are identified below in four main categories: Calgary statistics, traffic model data, budget data, and national transport data for Canada. A full list of data sources used for all cost calculations can be found in table 4, Appendix A.

Statistical information for Calgary included demographics such as population, employment information, and transportation mode share for automobiles and bicycles. Traffic count data used in this research included annual and daily automobile vehicle kilometres travelled (VKT) and daily bicycle trips from automated counters in two locations in the central business district (CBD). Annual collision statistics were also provided for automobiles and bicycles for a five year period from 2010 to 2014.

Information generated by the Calgary Regional Traffic Model (CRTL) was required to provide supplementary data in several areas: average trip distances for both automobiles and bicycles for various trip purpose categories, daily automobile and bicycle VKT, the ratio of personal automobile travel versus commercial travel, and the ratio of automobile trips for commuting versus utilitarian trips. Annual city-
wide vehicle emissions by vehicle type for 2015
were generated by the CALMOB emissions
model.

Budgetary information provided by The City of
Calgary included annual expenditures on
roadway and bridge maintenance related to
vehicular degradation of the road surface.
Additionally, expenditures on winter
maintenance, including snow clearing and
gravel sweeping for roadways and multi-use
pathways, were provided.

National data from various sources was required
to generate unit costs for transport and for
currency conversion. Reports from Transport
Canada provided information on air pollution
costs and the value of a statistical human life
(VSL) (Transport Canada, 2008), as well as
urban congestion costs (Transport Canada,
2006). Information from the Bank of Canada
and Statistics Canada were used for currency
conversion between national currencies and to
convert all cost values to 2015 Canadian dollars
using the historical consumer price index (CPI)
(Bank of Canada, n.d.; Statistics Canada, 1996;
Statistics Canada, 2016).

For several cost calculations the annual bicycle
VKT was required, though this data is not
generated by the CRTM nor calculated from
existing data counts. To generate an estimate for
the annual bicycle VKT, daily bicycle traffic
count data from two automatic counting
locations in the CBD were used, along with the
daily bicycle VKT estimate from the CRTM for
an “average fall weekday”. Normalizing the
daily bicycle count data to the weekday average
for September 2015 generated a ratio of the
number of bicycle trips per day compared with
this autumn weekday average value. Using this
ratio, it was then possible to estimate the city-
wide daily VKT for every day throughout 2015
based on the fall weekday VKT estimate from
the CRTM. Averaging the daily VKT estimates
between the two count locations in the CBD
captured a mix of bicycle trip types, as one
location was at the Peace Bridge, an important
connection between pathways adjacent to the
Bow River and on the border of the CBD (a
popular commuting and recreation route), and
the other was on Stephen Avenue, a pedestrian
mall within the CBD itself (and a key bicycle
commuting route). The daily averages of the
VKT estimates for both locations were summed
across the entire year to generate an estimate for
the annual bicycle VKT of approximately 63
million kilometres, which includes seasonal
variation. For comparison, the annual
automobile VKT for Calgary in 2015 was 9.8
billion kilometres. While this calculation
method produces an estimate for the annual
bicycle VKT, it is important to note that it is
based on the CRTM estimate for daily bicycle
VKT, which may not be as accurate as the
automobile VKT generated by the model, given
the much lower number of bicycle trips relative
to automobile trips.

Detailed information on data sources will be
provided for each of the cost categories in the
following section outlining how each of the cost
values were calculated.

3.3. Calculating Costs
Where possible, transportation data from
Calgary and Canada were used to generate unit
costs, with additional information and methods
from European and global research (see
Appendix A, table 4 for a complete list of the
data and research used in the calculations
completed for this project). For each of the
eleven cost categories, information will be
provided on data sources and how calculations
were carried out to determine both the internal
and external costs for both driving and cycling.
For all calculations conservative values were
chosen based on accepted and published data. All
costs were converted to 2015 Canadian
dollars.

3.3.1. Travel Time Costs
In order to calculate travel time costs on a per-
kilometre basis for driving and cycling, the
Copenhagen CBA framework identifies average
travel speeds for automobiles and bicycles as 50
km/h and 16 km/h respectively (COWI and City
of Copenhagen, 2009). The value of time for
personal travel (non-work, non-school) in
Calgary was taken from the CRTM at $12.04
(Martin, 2016).
Based on the value of time cost and the vehicle travel speeds, the travel time cost of driving and cycling were calculated to be $0.24/km and $0.75/km respectively. Both of these costs are personal costs borne by the user. The cost of cycling is more than 3 times the cost of driving on a per-kilometre basis due to the lower average speed of bicycle travel.

3.3.2. Vehicle Operating Costs
The vehicle operating cost calculations for driving and cycling are based on information from the Canada Revenue Agency and research from the Victoria Transportation Research Institute respectively (CRA, 2015; Littman & Doherty, 2011). Cost calculations for automobile and bicycle operations are explained separately below.

Automobile Operating Costs
In order to capture a conservative value for automobile operating costs without requiring a detailed breakdown of vehicle type, age, annual kilometres driven, cost of insurance, maintenance, and financing for the fleet of personal vehicles currently in use in Calgary, the automobile allowance rate for the province of Alberta was used as proxy. The vehicle allowance rate is set to compensate for costs associated with fuel purchase, vehicle financing, depreciation, and insurance. For 2015, the vehicle allowance rates were $0.55/km for the first 5000km and $0.49/km for all additional travel (CRA, 2015). The more conservative (i.e. less expensive) unit cost of $0.49/km was chosen for the automobile operating cost.

Bicycle Operating Costs
In order to capture the operating cost of a bicycle, research from the Victoria Transport Policy Institute’s report on Transportation Cost and Benefit Analysis (Littman & Doherty, 2011) indicates that several factors need to be considered, namely the purchase price of a bicycle, the estimated length of ownership, the yearly cost of repairs and maintenance, and the annual distance travelled. For the purposes of calculating a conservative bicycle operating cost the following values were used (Littman & Doherty, 2011): bicycle purchase price $1220, length of ownership 10 years, annual maintenance costs of $250, and annual distance travelled of 3200 km. Using these values results in a bicycle operating cost of $0.11/km. These values were from the top end of the range for costs presented by Littman & Doherty (2011), and are thus represent a more conservative (higher) bicycle operating cost.

3.3.3. Prolonged Life
Regular physical activity is beneficial for human health and can increase life expectancy (COWI and City of Copenhagen, 2009); (Kahlmeier et al., 2014). The World Health Organization (WHO) has gathered research and created a tool that calculates the economic benefits of cycling based on the reduced risk of all-cause mortality from exercise (Kahlmeier et al., 2014; WHO, 2014).

Using the online Health Economic Assessment Tool (HEAT) (WHO, 2014) with bicycle commuting mode share (1.39%) (The City of Calgary, 2014b), average one-way bicycle trip distance (4.46 km) (Martin, 2016), employment data for Calgary (Statistics Canada, 2015a), the age-standardized mortality rate for Alberta (5.0 per 1000 residents) (Statistics Canada, 2015b), and the value of a statistical life (VSL) from Transport Canada ($4.05 million) (Transport Canada, 2008) it was possible to calculate the reduced mortality rate for cyclists at 18%, preventing 8 deaths per year for those choosing to commute by bicycle with an economic benefit of approximately $30 million per year.

Using the annual bicycle VKT (Martin, 2016; Thivener & Glowacz, 2016) and the ratio of total bicycle trips to bicycle commuting trips from the CRTM, the total bicycle commuting VKT could be calculated (approximately 25 million km) (Martin, 2016). Using the bicycle commuting VKT, the per kilometre personal economic benefit of the reduced risk of mortality is -$1.18/km. This is a conservative value as it is the reduced mortality associated only with bicycle commuting, which does not include recreational cycling or utilitarian trips.

The negative cost value indicates that it is a net benefit. The effects of reduced mortality from
the physical activity associated with cycling are considered personal benefits rather than social benefits in the Copenhagen CBA framework (COWI and City of Copenhagen, 2009). In the Copenhagen CBA framework, there is a small cost associated with prolonged life attributed to cycling, this is due to the fact that with increased life expectancy there would be increased external costs to society to extend pension payments (COWI and City of Copenhagen, 2009). Given the relatively low number of cyclists in Calgary, the effect of reduced mortality on pensions for cyclists was excluded.

While cycling provides a net benefit to society with respect to prolonged life through physical activity, driving generates no reduction in mortality (COWI and City of Copenhagen, 2009), though including research into the mortality effects of driving may be part of future updates to the Copenhagen CBA framework and the unit costs generated by the Danish Transport Ministry.

3.3.4. Health

Active transportation provides health benefits through physical activity, reducing the risk of cardiovascular disease, several forms of cancer, type-2 diabetes, and depression (Genter et al., 2008; Littman & Doherty, 2011; Holm et al., 2012).

Information from the Victoria Transport Policy Institute (Littman & Doherty, 2011) and the New Zealand Transport Agency (Genter et al., 2008; NZ Transport Agency, 2016) provide a range of per-kilometre benefits to cycling where 50% of the benefit is internal to the cyclist and 50% of the benefit is felt to society at large. Unit rates from Genter, et al. (2008) were selected as they represented values in the middle of the range from the research identified by Littman and Doherty (2011). The internal and external health unit costs of cycling transport were each -$0.48/km, the negative value indicating private and social benefit rather than cost.

While bicycle travel does produce detrimental health impacts, namely exposure to air pollution and collisions, the health impacts related to increased physical activity outweigh the potential risks (Holm et al., 2012).

3.3.5. Collisions/Accidents

In order to calculate the cost of collisions for automobiles and bicycles, the methodology identified in the reports by European Commission’s (Maibach et al., 2008; Korzhenevych et al., 2014) was used as it is based on the value of a statistical life (VSL). A range of VSL for Canada were provided by Transport Canada (2008), the low value in this range was used ($4.05 million), as it is closer to the European Union averages used in the EU Commission documents.

In order to calculate the private and social costs of collisions, both the value of ‘safety per se’ and the direct and indirect economic costs of collisions need to be considered. These costs are expressed as varying percentages of VSL depending on the severity of collision (fatality, severe injury, and minor injury) (Maibach et al., 2008; Korzhenevych et al., 2014). Property damage only collisions were also examined, but as the collision statistics provided by The City of Calgary do not specify the cost of property damage, other than providing a minimum threshold, these collisions were not included. This means that the actual unit costs per kilometre for collisions underestimate the total costs. Further research may allow inclusion of these costs if adequate statistical data can be obtained.

The value of ‘safety per se’ for fatalities, severe injuries, and minor injuries are 100%, 13%, and 1% of VSL respectively. The direct and indirect economic costs of fatalities, severe injuries, and minor injuries are 10%, 1.3%, and 0.1% of VSL respectively (Maibach et al., 2008; Korzhenevych et al., 2014).

Treatment of internal and external costs varied between automobiles and bicycles. For automobiles, it was assumed that both the risk value of ‘safety per se’ and the direct and indirect economic impacts were external to the user and could be considered social costs. This assumption is based on the fact that insurance
paid by vehicle owners as part of their vehicle operating costs covers the damages resulting from a collision, and that society at large will bear the direct and indirect economic impacts of an automobile collision.

Given that bicycles do not require insurance, for the purposes of this research, the risk cost of collisions, or ‘safety per se’ is assumed to be borne directly by the cyclist. The direct and indirect economic costs of collisions were considered to be external to the cyclist and included as a social cost.

It should be noted here that further development of this appropriation of costs to automobiles and cyclists is required. As stated by Gössling & Choi (2015), the material damages of bicycle collisions are generally lower than for automobile collisions, and the exposure of cyclists to risk in a collision is much higher. Finding a way to reflect this imbalance in risk for cyclists would help to properly calculate costs. Another issue related to bicycle collision is that if a bicycle is involved in a collision with a motorist and they are not at fault, the automobile driver’s insurance would be expected to cover the associated collision costs. Examining collision statistics in greater depth to determine the fault of collisions would allow for the proper allocation of those costs of collisions to the appropriate mode.

Collision statistics were provided by The City of Calgary in the Traffic Collision Annual Report 2014 (Caufield, 2016; The City of Calgary, 2015b). Five-year averages were calculated for each collision category and used in the unit cost calculations for driving and cycling.

Following the method outlined by the European Commission, the average number of reported collisions were multiplied by correction factors to compensate for unreported collisions for driving and cycling and for each collision type (Maibach et al., 2008).

Once the corrected average number of collisions by type were calculated, these values were multiplied by the value of ‘safety per se’ and direct and indirect economic costs, (based on VSL) to get a total annual cost, which was then divided by the annual VKT for each mode.

The average social costs of collisions for driving were calculated to be $0.04/km. For cycling, the average personal cost of collisions was calculated to be $1.22/km, and the social cost calculated to be $0.12/km.

3.3.6. Air Pollution

Air pollution emissions from automobiles contain both gaseous and particulate materials such as nitrogen oxides (NOx), volatile organic compounds (VOC), sulphur oxides (SO2), carbon monoxide (CO), and particulate matter (PM10 and PM2.5) (Korzhenevych et al., 2014)

Transport Canada identifies the unit cost per tonne of several pollutants for health impacts (based on a damage function approach in a valuation model from Health Canada), visibility (using a model by Environment Canada linking PM2.5 concentrations to visibility), and agricultural impacts (using a model by Environment Canada linking crop productivity to the presence of ozone (O3) (Transport Canada, 2008)). Unit costs were provided for NOx, VOC, SO2, and PM2.5.

Automobile emission data was provided by The City of Calgary’s CALMOB emissions model, which estimated the total air pollution emissions by personal automobiles in 2015 for carbon dioxide (CO2), carbon monoxide (CO), nitrogen oxides (N2O), non-methane hydrocarbons (NMHC), and particulate matter (PM10) (Martin, 2016; The City of Calgary, 2016; Van Boom, 2016).

As can be seen, there is not a complete match between the pollutant output generated by the model and the unit costs provided by Transport Canada. To calculate the unit cost for air pollution for vehicular transport, some pollutants were excluded (CO, SO2, PM2.5, PM10) from this assessment as either costs or emission levels were not available, resulting in an underestimation of the total cost of vehicular pollution for transport. For the calculation for VOC, NMHC was used, as it is a subset of VOC
(Petrea et al., 2005), though this represents another cost underestimation.

Using the modelled 2015 emissions from personal vehicles (Martin, 2016; The City of Calgary, 2016; Van Boom, 2016) and the annual VKT for personal vehicle travel (excluding commercial travel) (Caufield, 2016; Martin, 2016; Tahmasseby, 2016) it was possible to calculate the average cost of air pollution for personal vehicle travel at $0.001/km. As this value does not include the costs associated with several pollutants it represents an underestimation of the actual cost.

3.3.7. Climate Change

Climate change impacts of transportation are social costs resulting from the emission of greenhouse gasses (GHG), namely carbon dioxide (CO$_2$), nitrous oxide (N$_2$O), and methane (CH$_4$) (Maibach et al., 2008). While a great deal of uncertainty exists in determining the cost of climate change there was alignment between Canadian and European methodologies in that they are based on the price of carbon on the European Carbon Exchange (Transport Canada, 2008; Maibach et al., 2008; Korzhenevych et al., 2014).

The cost of carbon used in this calculation is based on the avoidance costs of the efforts required to stabilize global warming at 2°C, with a median value of €90/tonne (€2010) of CO$_2$ (Korzhenevych et al., 2014). This corresponds to a cost in SCAD 2015 of approximately $135/tonne CO$_2$, more than a three-fold increase from the values used by Transport Canada of $39/tonne CO$_2$ based on the 2006 European carbon market price range of €15-€30/tonne CO$_2$ (Transport Canada, 2008). For the purposes of this study, the updated price of carbon was used.

In order to calculate the unit cost of climate change, the total annual CO$_2$ and NOx emissions for private vehicle use were used along with the annual VKT for personal vehicle trips (Caufield, 2016; The City of Calgary, 2016; Tahmasseby, 2016). The total annual NOx emissions were multiplied by the global warming potential (GWP) of N$_2$O relative to CO$_2$ (310 times more effective than CO$_2$ at trapping heat in the atmosphere (Terefe, 2010)) to determine the CO$_2$ equivalent of the NOx emissions. N$_2$O in this case can be used as a surrogate for the NOx family of compounds in order to calculate the equivalent CO$_2$ emissions (U.S. EPA, 1999). Once the total CO$_2$ and equivalent CO$_2$ from NOx emissions were combined, the total value (3.5 million tonnes) was multiplied by the market price for carbon emission and divided by the total VKT for personal vehicle travel in Calgary.

Using the Transport Canada (2008) value for carbon of $39/tonne CO$_2$, the resulting unit cost of climate change from driving a personal vehicle is $0.015/km. When using the updated cost of CO$_2$ at $135/tonne, the per-kilometre social cost of climate change from personal vehicle use in Calgary increased to $0.053/km.

3.3.8. Noise

The cost of noise from vehicular traffic consists of two elements: the cost of annoyance and the cost of health impacts due to noise exposure (Maibach et al., 2008; Korzhenevych et al., 2014). The cost of annoyance can be calculated using stated or revealed preference methods (Transport Canada, 2008), or hedonic price surveys of the impact of traffic noise on residential property value (Maibach et al., 2008). Health impacts from noise include sleep disturbance, acute myocardial infarction, and hypertension (Korzhenevych et al., 2014). These are social costs, external to the road user (COWI and City of Copenhagen, 2009).

While the EU Commission handbook (Korzhenevych et al., 2014) provides a detailed cost table for marginal cost of noise based on vehicle and roadway type as well as time of day, an aggregate cost value stating the average cost of noise generated was needed for this study, as it is dealing with costs averaged over an entire city. Automobile noise costs for an average car were estimated at $0.016/km in a Canadian report by the Victoria Transport Policy Institute based on existing cost estimates from international research (Littman & Doherty, 2011). The $0.016/km cost of noise was selected, as it was the most recent and
appropriate data available from Canadian research.

3.3.9. Road Deterioration
Vehicular traffic damages roadways and associated infrastructure such as bridges. In the Copenhagen CBA framework, the cost of road degradation by vehicles used the total annual cost of contracts for roadway repairs undertaken (not capital construction of new roads or expansion of existing roads) (COWI and City of Copenhagen, 2009). Using a similar method, the total 2015 expenditures for The City of Calgary related to roadway maintenance were summed for asphalt and gravel roadway resurfacing and reconstruction, as well as bridge repairs, totalling approximately $29 million per year (Arthur, 2016). Using these expenditure values and the annual automobile VKT (9.8 billion km) (Caufield, 2016) (Tahmasseby, 2016) the average social cost of road deterioration per kilometre driven was calculated at $0.003/km.

Roadway deterioration directly caused by bicycle traffic is considered negligible (COWI and City of Copenhagen, 2009) and is not included as a cost for cycling transport.

3.3.10. Congestion
Transportation Canada has adopted the following definition of congestion: “Congestion is the inconvenience that travellers impose on each other while using their vehicles and attempting to use the road network at the same time, because of the relationship that exists between traffic density and speed (with due consideration of capacity).” (Transport Canada, 2006, p.6). Quantification of the annual social costs of congestion was developed by Transport Canada for nine Canadian cities, including Calgary (Transport Canada, 2006).

In the research by Transport Canada, congestion on expressways and arterial roads were considered for personal automobile travel, the low range of the total cost of congestion was chosen as a conservative estimate for this research, approximately $120,000,000 for 2001 (in 2015 dollars) (Transport Canada, 2006). Given that the population in Calgary expanded from less than 900,000 in 2001 to more than 1.2 million in 2015 (The City of Calgary, 2015a), the congestion costs in 2015 would likely be significantly higher. Using the total annual cost of congestion and the annual automobile VKT (Caufield, 2016; Tahmasseby, 2016), the per kilometre unit cost of congestion was calculated as $0.013/km, though this is likely an underestimation given the increase in population from the time of the Transport Canada study on the cost of congestion in 2001 and today.

As in the Copenhagen CBA framework, it is assumed that bicycles do not generate congestion costs. (COWI and City of Copenhagen, 2009)

3.3.11. Winter Maintenance
Based on 30-year climate averages, Calgary could be considered a “winter city”. In Calgary there are 86 days per year where more than one centimetre of snow is on the ground, 54 days a year with measurable snowfall, annual snowfall of nearly 130cm, and 194 days a year where the minimum daily temperature drops below 0°C (Government of Canada, 2015). Winter maintenance of roads in Calgary represents a significant societal cost, and it is appropriate to include it in calculations related to the cost of driving and cycling in the city.

Using the annual budget information for winter snow and ice control and spring time gravel sweeping (approximately $42 million per year) (Arthur, 2016), in combination with the annual automobile VKT (Caufield, 2016; Tahmasseby, 2016), the social cost of winter maintenance for automobile traffic is $0.004/km.

Winter maintenance of on-street bicycle facilities is included with the roadway winter maintenance budget, though the costs associated with the maintenance of the bicycle facilities are not identified separately (Arthur, 2016). There is a large network of multi-use pathways maintained throughout the winter on key routes however, and using this cost (Tucker, 2016) with the annual bicycle VKT (Martin, 2016; Thivener & Glowacz, 2016), the per kilometre social cost for winter maintenance of bicycle facilities was calculated to be $0.006/km.
Further research is needed to more accurately determine the costs of winter maintenance of both on and off-street bicycle facilities.

4. Results

The complete results for all cost categories are included in Table 1. Private and social costs are identified separately (all values are expressed in 2015 Canadian dollars per kilometre travelled). For cycling, the private costs paid by the cyclist for every kilometre travelled is $0.43, the social costs per kilometre travelled are -$0.35 (the negative value denotes a benefit rather than a cost), with the total cost for every kilometre travelled by bicycle being $0.08.

For personal automobile use, the private costs borne by the driver per kilometre driven are $0.73, the social costs per kilometre driven are $0.10, with the total cost of driving equal to $0.83 per kilometre.

Based on the calculations completed for this research, the total estimated cost of driving is over ten times higher than the cost of cycling per kilometre travelled.

Returning to the original aims of this research, it has been shown to be possible to determine the costs of driving and cycling in Calgary based on the Copenhagen CBA framework. Using real-world data as well as research and methodology from Canada and around the world, the private and social costs of transport were calculated across a range of impact categories.

This research has also shown that it is possible to adapt the Copenhagen CBA framework for the Calgary context, specifically through the inclusion of winter maintenance of the transportation network.

The Copenhagen CBA framework provided a suitable starting point for calculating the costs of both driving and cycling transportation in Calgary.

5. Discussion

While calculating the costs of driving and cycling in Calgary was shown to be possible through this research project, further exploration of the results is needed. Key findings from the results of this study will be discussed below, as well as comparison of these results with data from Copenhagen. Potential applications of the results of this research in the Calgary context will also be discussed.

When examining the results of the unit cost calculations, particularly for cycling, it can be seen that the costs for travel time and collisions represent a significant portion of personal costs borne by the cyclist. As a slower mode of transport, the high travel time cost is easily understood as the result of lower travel speed. The high cost of accidents however must be considered with respect to two issues: attribution of all of the risk cost of ‘safety per se’ to cyclists, and the relatively low annual bicycle VKT. More detailed information is needed about cyclist collisions to determine a
more accurate method to attribute the cost of ‘safety per se’ between cyclists and automobiles. An example of the type of information that could shed light on the matter is statistical data on whether the cyclist is considered at fault in a collision. If at fault, the collision costs should be attributed to the cyclist, whereas if the fault of the collision is attributed to the automobile, the costs should be included in the collision unit cost for automobiles. Regarding the relatively low annual VKT travelled by bicycle, by increasing the amount that people cycle, the average collision cost per kilometre travelled would decrease, as well as increasing the overall level of safety for cyclists, the so called ‘safety in numbers’ effect (Andersen et al., 2012; Meschik, 2012).

The relatively high cost of travel time and collisions for bicycle travel is largely offset however by the benefits brought about by physical activity through prolonged life (reduced risk of mortality) and health (reduced risk of morbidity). The social costs of cycling are -$0.35 per kilometre, indicating a net benefit to society for every kilometre travelled, whereas the social costs associated with driving one kilometre are $0.10 and produce several negative effects such as air pollution, climate change, noise, roadway degradation, and congestion.

When the unit costs for winter maintenance were calculated for driving and cycling, the values were very low relative to the other unit costs produced, at $0.004 and $0.006 per kilometre travelled by car and bicycle respectively. While these represent a small component of the total social costs for these modes of transport, and while the data used to generate these costs did not have the level of detail necessary to attribute costs as comprehensively as possible, it does show that the Copenhagen CBA framework can be modified to suit local conditions, creating a clearer picture of the costs of transport.

Table 2 includes the average cost per kilometre of driving and cycling from Copenhagen’s CBA framework (COWI and City of Copenhagen, 2009) with values converted to 2015 Canadian dollars so as to be comparable to the results of this study.

The average costs of driving and cycling in Copenhagen are $0.87 and $0.14 per kilometre, respectively. These aggregated results match closely with the results from Calgary, though there are some key differences. A summary of the private and social costs of driving and cycling in both Calgary and Copenhagen are included in table 3, as well as tables 5 and 6 in Appendix B.

Travel time costs for both driving and cycling are higher in Copenhagen than in the results from Calgary, likely owing to a higher value of time for personal travel. The social cost of congestion for automobile travel was more than
two times higher in Copenhagen compared with Calgary. This may be a result of the fact that the cost of congestion in Calgary was based on congestion data from 2001 (Transport Canada, 2006), likely representing an underestimation of the actual current cost of congestion as the population has increased by nearly 40% in the intervening years (The City of Calgary, 2014b).

Table 3: Summary of the Private and Social Costs of Driving and Cycling in Calgary and Copenhagen (in 2015 Canadian dollars per kilometre travelled). Note that duties paid on private automobile operation costs in Copenhagen are not included in this table, though it is included in the total cost.

<table>
<thead>
<tr>
<th></th>
<th>Calgary</th>
<th>Copenhagen</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cycling</td>
<td>Private Costs</td>
<td>$0.43</td>
<td>$0.42</td>
</tr>
<tr>
<td></td>
<td>Social Costs</td>
<td>-$0.55</td>
<td>-$0.28</td>
</tr>
<tr>
<td></td>
<td>Total Costs</td>
<td>$0.08</td>
<td>$0.14</td>
</tr>
<tr>
<td>Driving</td>
<td>Private Costs</td>
<td>$0.73</td>
<td>$0.88</td>
</tr>
<tr>
<td></td>
<td>Social Costs</td>
<td>$0.10</td>
<td>$0.26</td>
</tr>
<tr>
<td></td>
<td>Total Costs</td>
<td>$0.83</td>
<td>$0.87</td>
</tr>
</tbody>
</table>

The cost associated with traffic noise was five times higher in Copenhagen than in Calgary, which could be a result of the higher urban density in Copenhagen and the highly aggregated unit cost used in Calgary from research done by the Victoria Transport Policy Institute (Littman & Doherty, 2011).

While the average benefit of prolonged life per kilometre cycled is higher in Calgary, potentially affected by lower annual bicycle VKT over which the benefits are averaged, the Copenhagen CBA framework also includes a social cost of prolonged life. This cost is associated with increased pensions due to longer life. The potential societal cost of prolonged life with respect to pensions was not included in the Calgary calculations due to a lack of appropriate data, and the relatively small number of cyclists whose commuting activity was used in the online Health Economic Assessment Tool (HEAT) (WHO, 2014).

The average cost of air pollution in the Copenhagen CBA framework was an order of magnitude higher than in the Calgary calculations. This reflects a lack of data produced in the annual emissions reports from the CRTM (Littman & Doherty, 2011), namely the total emissions of SO₂ and PM₂.₅, and the lack of a unit cost for PM₁₀ emissions developed using Transport Canada’s damage function approach for determining health impacts of pollution (Transport Canada, 2008).

The most significant structural difference between the Copenhagen CBA and the Calgary calculations is the inclusion of duties in Copenhagen, calculated at -$0.27 per kilometre travelled by car. Duties and taxes were excluded from Calgary’s calculations as the automobile allowance rate for Alberta was used as a proxy for the costs associated with vehicle operation, namely fuel purchase, vehicle financing, depreciation, and insurance. With a more detailed calculation of vehicle operating costs, based on the information on the vehicle fleet composition in Calgary and annual distance driven, the impacts of taxes on unit cost calculations could be explored. Taxes and duties were also included in the health benefits in the Copenhagen CBA framework, responsible for the difference between personal and social benefits, whereas in Calgary the allocation was 50% personal benefit, and 50% social benefit.

This research has shown that the Copenhagen CBA framework can be applied in Calgary, generating per kilometre unit costs for driving and cycling that includes cost externalities not generally considered in traditional CBA. The results of this research could be applied in several areas in Calgary: in support of policies aimed at increasing cycling levels, in planning decisions related to bicycle infrastructure implementation, for use as input values in traditional CBA for new transportation infrastructure projects, or combined with transportation model projections to quantify social and environmental impacts in triple-bottom-line analyses.

In order to create more accurate and comprehensive unit cost calculations for driving and cycling in Calgary it is recommended that future research be undertaken in two key areas: appropriately attributing risk cost of collisions between cars and bicycles, and further exploration of air pollution emissions costs related to personal automobile travel.
6. Conclusion
This research has shown that it is possible, using the Copenhagen CBA framework as a guide, to develop a model that can calculate the costs of driving and cycling in Calgary based on real world data and current research from Canada and elsewhere.

The average private cost per kilometre of driving and cycling were calculated to be $0.73 and $0.43 respectively, the average social cost per kilometre of driving and cycling are $0.10 and -$0.35 respectively, highlighting the fact that cycling for transportation generates net benefits for society. When private and social costs are combined, the per kilometre costs of driving and cycling in Calgary are $0.83 and $0.08 respectively, illustrating the disparity in costs for these two modes of transport.

By including costs related to winter maintenance of transportation infrastructure it was possible to modify the impact categories included in the Copenhagen CBA framework to more accurately reflect the local conditions found in Calgary. The fact that the Copenhagen CBA framework could be modified in this way demonstrates that the method is applicable not only in jurisdictions outside of Denmark, but outside of the European Union.

Facilitating automobile transport is a critical aspect of urban transportation networks and systems, however in an increasingly urbanized and resource constrained world it is important to support a broad mix of transportation options, particularly active transportation such as cycling. When analysing investments in infrastructure and exploring changes to policy related to transportation, it is important to consider environmental, social and economic impacts. Tools such as the CBA framework developed in Copenhagen can help to illuminate a broader range of impacts related to transportation and help guide decision makers in the development of more accessible, resilient, and sustainable transportation networks.

7. Acknowledgement
This thesis project was inspired by the recent work of Stefan Gössling, fortunately, Stefan was able to supervise this project I would like to thank him for his assistance and guidance. Thanks also go to Martin Gren for supporting this project as an evaluator.

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8. References


Parliamentary Commissioner for the Environment, 2002. Creating our future:


## Appendix A – Data Sources for Cost Calculations

### Table 4: Data sources used to calculate the private and social costs of driving and cycling in Calgary.

<table>
<thead>
<tr>
<th>Cost Category</th>
<th>Information Required</th>
<th>Travel Mode</th>
<th>Data Source(s)</th>
<th>Organization(s)</th>
<th>Citation</th>
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<tbody>
<tr>
<td><strong>Travel Time Cost</strong></td>
<td>Bicycle Operating Speeds</td>
<td>Bicycle, Automobile</td>
<td>Transportation Cost and Benefit Analysis - Techniques, Estimates and Implications</td>
<td>Victoria Transport Policy Institute</td>
<td>(Littman &amp; Doherty, 2011)</td>
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<td>Value of Time</td>
<td>Bicycle, Automobile</td>
<td>Calgary Regional Transportation Model v2</td>
<td>The City of Calgary</td>
<td>(Martin, 2016)</td>
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<td><strong>Vehicle Operation Cost</strong></td>
<td>Bicycle Operating Cost</td>
<td>Bicycle</td>
<td>Estimates of the Full Cost of Transportation in Canada</td>
<td>Transport Canada</td>
<td>(Transport Canada, 2008)</td>
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<tr>
<td></td>
<td>Effects of Physical Activity on Reduced Mortality</td>
<td>Bicycle</td>
<td>Health Economic Assessment Tool (HEAT)</td>
<td>World Health Organization (WHO)</td>
<td>(WHO, 2014)</td>
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<td>Value of a Statistical Human Life (VSL)</td>
<td>Bicycle</td>
<td>Estimates of the Full Cost of Transportation in Canada</td>
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<td>(Transport Canada, 2008)</td>
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<td>Statistics Canada</td>
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<td>Calgary Regional Transportation Model v2, Automatic Bicycle Count Data</td>
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<td>Calgary Regional Transportation Model v2</td>
<td>(Tahmasseby, 2016)</td>
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<td>Victoria Transport Policy Institute</td>
<td>(Littman &amp; Doherty, 2011); (<a href="#">Genter et al., 2008</a>)</td>
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<td>Handbook on estimation of external costs to the transport sector Initialization Measures and Policies for All external Cost of Transport (IMPACT); Update of the Handbook on External Costs of Transport</td>
<td>European Commission</td>
<td>(Maibach et al., 2008)</td>
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<tr>
<td></td>
<td>Annual Automobile Vehicle Kilometres Traveled (VKT)</td>
<td>Bicycle, Automobile</td>
<td>Calgary Regional Transportation Model v2</td>
<td>The City of Calgary</td>
<td>(Caufield, 2016); (<a href="#">Tahmasseby, 2016</a>)</td>
</tr>
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<td></td>
<td>Unit Costs of Air Pollutants in Calgary from Personal Automobiles</td>
<td>Bicycle</td>
<td>Estimates of the Full Cost of Transportation in Canada</td>
<td>Transport Canada</td>
<td>(Transport Canada, 2008)</td>
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<tr>
<td></td>
<td>Annual Emissions of Air Pollutants in Calgary</td>
<td>Bicycle</td>
<td>2015 Emissions Report; CALMOM Emissions Model; Calgary Regional Transportation Model v2</td>
<td>The City of Calgary</td>
<td>(Martin, 2016); (<a href="#">Van Boom, 2016</a>)</td>
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<tr>
<td></td>
<td>Annual Automobile Vehicle Kilometres Traveled (VKT)</td>
<td>Bicycle</td>
<td>2015 VKT Report</td>
<td>The City of Calgary</td>
<td>(Caufield, 2016); (<a href="#">Tahmasseby, 2016</a>)</td>
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<tr>
<td></td>
<td>Unit Cost of CO2 Equivalent Emissions</td>
<td>Bicycle</td>
<td>Estimates of the Full Cost of Transportation in Canada; Update of the Handbook on External Costs of Transport</td>
<td>Transport Canada; European Commission</td>
<td>(Transport Canada, 2008); (<a href="#">Korzhenevych et al., 2014</a>)</td>
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<tr>
<td><strong>Air Pollution</strong></td>
<td>Annual Emissions of Air Pollutants in Calgary from Personal Automobiles</td>
<td>Bicycle</td>
<td>2015 Emissions Report; CALMOM Emissions Model; Calgary Regional Transportation Model v2</td>
<td>The City of Calgary</td>
<td>(Martin, 2016); (<a href="#">The City of Calgary, 2016</a>); (<a href="#">Van Boom, 2016</a>)</td>
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<td></td>
<td>Annual Automobile Vehicle Kilometres Traveled (VKT)</td>
<td>Bicycle</td>
<td>2015 VKT Report</td>
<td>The City of Calgary</td>
<td>(Caufield, 2016); (<a href="#">Tahmasseby, 2016</a>)</td>
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<td></td>
<td>Ratio of Personal Trips to Commercial Trips by Automobile</td>
<td>Bicycle</td>
<td>Calgary Regional Transportation Model v2</td>
<td>The City of Calgary</td>
<td>(Martin, 2016)</td>
</tr>
<tr>
<td></td>
<td>Unit Cost of CO2 Equivalent Emissions</td>
<td>Bicycle</td>
<td>Estimates of the Full Cost of Transportation in Canada; Update of the Handbook on External Costs of Transport</td>
<td>Transport Canada; European Commission</td>
<td>(Transport Canada, 2008); (<a href="#">Korzhenevych et al., 2014</a>)</td>
</tr>
<tr>
<td><strong>Climate Change</strong></td>
<td>Global Warming Potential (GWP) of Greenhouse Gases</td>
<td>Bicycle</td>
<td>Global Warming Potential (GWP) of Greenhouse Gases</td>
<td>Statistics Canada</td>
<td>(Treffe, 2010)</td>
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<tr>
<td></td>
<td>Annual Emissions of Air Pollutants in Calgary from Personal Automobiles</td>
<td>Bicycle</td>
<td>2015 Emissions Report; CALMOM Emissions Model; Calgary Regional Transportation Model v2</td>
<td>The City of Calgary</td>
<td>(Martin, 2016); (<a href="#">The City of Calgary, 2016</a>); (<a href="#">Van Boom, 2016</a>)</td>
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<tr>
<td><strong>Noise</strong></td>
<td>Average Cost of Automobile Noise in Urban Areas</td>
<td>Bicycle</td>
<td>Transportation Cost and Benefit Analysis - Techniques, Estimates and Implications</td>
<td>Victoria Transport Policy Institute</td>
<td>(Littman &amp; Doherty, 2011)</td>
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<tr>
<td><strong>Roadway Deterioration</strong></td>
<td>Annual Budget for Roadway Surface Repair and Reconstruction</td>
<td>Automotive</td>
<td>Road Department 2015 Budget</td>
<td>The City of Calgary</td>
<td>(<a href="#">Arthur, 2016</a>)</td>
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<td><strong>Congestion</strong></td>
<td>Annual Cost of Congestion in Calgary</td>
<td>Automotive</td>
<td>The Cost of Urban Congestion in Canada</td>
<td>Transport Canada</td>
<td>(Transport Canada, 2008)</td>
</tr>
<tr>
<td><strong>Winter Maintenance</strong></td>
<td>Annual Snow and Ice Control Budget</td>
<td>Bicycle</td>
<td>Parks Pathways Snow Clearing Budget</td>
<td>The City of Calgary</td>
<td>(Tucker, 2016)</td>
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<tr>
<td></td>
<td>Annual Bicycle Kilometres Traveled (VKT)</td>
<td>Bicycle</td>
<td>Calgary Regional Transportation Model v2, Automatic Bicycle Count Data</td>
<td>The City of Calgary</td>
<td>(Martin, 2016); (<a href="#">Tahmasseby, 2016</a>); (<a href="#">Nyström &amp; Glowacz, 2016</a>)</td>
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</table>
Appendix B – Comparing Costs: Calgary and Copenhagen

Table 5: Comparison of the private and social costs (in 2015 Canadian dollars) per kilometre travelled by bicycle in Calgary and Copenhagen.

<table>
<thead>
<tr>
<th>Category</th>
<th>Private Costs</th>
<th>Social Costs</th>
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<tbody>
<tr>
<td></td>
<td>Calgary</td>
<td>Copenhagen</td>
</tr>
<tr>
<td>Time Costs (travel time, non-work)</td>
<td>$0.75</td>
<td>$1.16</td>
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<tr>
<td>Vehicle Operating Costs</td>
<td>$0.11</td>
<td>$0.08</td>
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<tr>
<td>Prolonged Life</td>
<td>-$1.18</td>
<td>-$0.62</td>
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<tr>
<td>Health</td>
<td>-$0.48</td>
<td>-$0.26</td>
</tr>
<tr>
<td>Accidents/Collisions</td>
<td>$1.22</td>
<td>$0.06</td>
</tr>
<tr>
<td>Branding/Tourism</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Winter Maintenance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>$0.43</td>
<td>$0.42</td>
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Table 6: Comparison of the private and social costs (in 2015 Canadian dollars) per kilometre travelled by automobile in Calgary and Copenhagen.

<table>
<thead>
<tr>
<th>Category</th>
<th>Private Costs</th>
<th>Social Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Calgary</td>
<td>Copenhagen</td>
</tr>
<tr>
<td>Time Costs (travel time, non-work)</td>
<td>$0.24</td>
<td>$0.37</td>
</tr>
<tr>
<td>Vehicle Operating Costs</td>
<td>$0.49</td>
<td>$0.51</td>
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<tr>
<td>Accidents/Collisions</td>
<td></td>
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<tr>
<td>Air Pollution</td>
<td>$0.001</td>
<td>$0.01</td>
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<td>Climate Change</td>
<td>$0.02</td>
<td>$0.01</td>
</tr>
<tr>
<td>Noise</td>
<td>$0.016</td>
<td>$0.08</td>
</tr>
<tr>
<td>Road Deterioration</td>
<td>$0.003</td>
<td>$0.002</td>
</tr>
<tr>
<td>Congestion</td>
<td>$0.01</td>
<td>$0.11</td>
</tr>
<tr>
<td>Winter Maintenance</td>
<td>$0.004</td>
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</tr>
<tr>
<td>Total</td>
<td>$0.73</td>
<td>$0.88</td>
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</tbody>
</table>

Appendix C – List of Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Meaning</th>
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<tbody>
<tr>
<td>CBA</td>
<td>Cost-Benefit Analysis</td>
</tr>
<tr>
<td>CBD</td>
<td>Central Business District</td>
</tr>
<tr>
<td>CRA</td>
<td>Canada Revenue Agency</td>
</tr>
<tr>
<td>CRTM</td>
<td>Calgary Regional Transportation Model (version 2)</td>
</tr>
<tr>
<td>GWP</td>
<td>Global Warming Potential</td>
</tr>
<tr>
<td>HEAT</td>
<td>Health Economic Assessment Tool</td>
</tr>
<tr>
<td>NMHC</td>
<td>Non-Methane Hydrocarbon</td>
</tr>
<tr>
<td>PM</td>
<td>Particulate Matter</td>
</tr>
<tr>
<td>TBL</td>
<td>Triple Bottom Line</td>
</tr>
<tr>
<td>U.S. EPA</td>
<td>United States Environmental Protection Agency</td>
</tr>
<tr>
<td>VKT</td>
<td>Vehicle Kilometres Traveled</td>
</tr>
<tr>
<td>VOC</td>
<td>Volatile Organic Compound</td>
</tr>
<tr>
<td>VSL</td>
<td>Value of a Statistical Life</td>
</tr>
<tr>
<td>VTPI</td>
<td>Victoria Transport Policy Institute</td>
</tr>
<tr>
<td>WHO</td>
<td>World Health Organization</td>
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