

Have we reached peak driving?:
A 25-year decomposition of vehicle trends in Canada

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ABSTRACT

The external costs of vehicle use are extensive, including traffic accidents, urban congestion, air pollution, and greenhouse gas emissions. Around the turn of the millennia, after decades of steady growth, per capita vehicle use in many western countries plateaued, or even declined. As there has been very little research conducted on Canadian driving patterns, this study aims to determine whether vehicle use has been changing in Canada, and how it compares to the United States. This research seeks to explain the influential factors behind vehicle use, specifically the effect of an aging population, rising income and gas prices, urbanization, and other elements. An index decomposition analysis was applied to weigh the relative influence of population growth, demographic changes, and individual car use, in both Canada and the United States, which was followed by a fixed-effect regression analysis to determine the influence of gas prices, income, and urbanization. Our results found that Canada has not experienced the same remarkable change in vehicle use compared to other western countries, but only a modest peak or plateau, with young adults leading the trend. Gas prices appear to be responsible for some of the change, although this was offset by the positive influence of population growth, and rising incomes. Although the quality of data needs to be improved, understanding driving trends in Canada can help policy makers manage vehicle use and its numerous associated externalities.

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INTRODUCTION

Canada's automobile dependency has had a notable effect on climate and air quality. Road transportation accounts for 23% of all greenhouse gases in Canada (Environment and Climate Change Canada 2014), and is responsible for a substantial proportion of smog production (Environment and Climate Change Canada 2016). In addition, vehicle travel is responsible for thousands of traffic fatalities and serious injuries per year in Canada (Transport Canada 2015), and costs billions of dollars in lost productivity as a result of urban congestion (Transport Canada 2006).

Car use, measured as kilometres travelled by personal vehicles, was steadily increasing since the emergence of the automobile at the turn of the 20th century. Yet in the early 2000s, for the first time, car use stopped growing in the United States (Puentes and Tomer 2008), Australia (Stanley and Barrett 2010), the United Kingdom (Metz 2010; Metz 2013; Le Vine et al. 2009), Germany, and France (Kuhnimhof et al. 2013), among other countries (Millard-Ball and Schipper 2011). The trend is particularly apparent among younger generations (Kuhnimhof et al. 2012, Kuhnimhof et al. 2013; Goodwin and Van Dender 2013). Various theories have been proposed to explain the change in driving behaviour, including economic factors such as the 2008 recession and increased gas prices, changing demographics, shifts in youth culture, and urbanization, among others (Goodwin 2012A).

As the baby boomers age, Canada's senior population is growing (Employment and Social Development Canada 2016A), a demographic that has historically driven less (US EIA 2013; Dutzik and Baxandall 2013). Canada is also becoming more urbanized, with Ontario, British Columbia and Alberta housing the largest proportion of urban dwellers (Employment and Social Development Canada 2016B), who also typically drive less (Newman and Kenworthy 2006). However, to date, very little research has

been conducted on trends of travel demand and driving behaviour in Canada, nor has there been much research attempting to quantify the relative impacts of potential factors influencing vehicle use.

This research aims to determine if vehicle use has been changing within the last 20 years in Canada, consistent with other OECD countries, and how these trends compare between provinces and the United States. This research also seeks to explain the influential factors behind vehicle use and to quantify the relative contributions of an aging population, changing driving preferences, economic factors, and other elements of vehicle use in Canada and the United States.

Time series data were collected from Natural Resources Canada, Transport Canada, Statistics Canada, and provincial transportation ministries and auto insurance agencies, and aggregate trends in vehicle kilometres were decomposed using an index decomposition analysis. A logarithmic Divisia mean index was applied to quantify the relative contributions of factors affecting car use, including population growth, changing age structure of the population, licensing rates, and vehicle kilometres travelled by different age groups. Trends were decomposed at a national level and compared with American vehicle use. Next, a multiple regression analysis was undertaken to estimate the relationship between Canadian vehicle travel and several other variables, including gas price, income, and the population share in urban centres.

We found that per capita vehicle kilometres travelled in Canada have not experienced the same remarkable change compared to other western countries. For instance, American per capita vehicle use was growing steadily until the early 2000s, after which it began to level off and decrease. Comparatively, Canada experienced only a modest peak or plateau, although some provinces exhibited a decline while others experienced an increase. In both the U.S. and Canada, the decline or plateau in vehicle use can be attributed to changes in individual behaviour, where people are driving less, especially young adults.

This decline was offset by population growth and growing incomes, both of which are increasing across North America. Alternatively, gas prices appear to be responsible for pushing vehicle use downwards in Canada. The effect of an aging population is having little to no effect on driving trends in North America. Finally, the regression analysis suggests that the effect of increasing urbanization in Canada is having no effect on driving trends, although this may be the result of low variability and/or inaccurate data, rather than actual settlement patterns.

Although it is impossible to predict future trends in transportation, understanding the possible factors influencing driving behaviour in Canada will help provide more accurate projections and considerations for transportation and land-use planning, fuel consumption projections, and climate mitigation. Understanding why driving preferences have changed over the last 25 years can help policy makers manage vehicle use and the numerous associated externalities.

LITERATURE REVIEW

External Costs of Automobile Dependence

Since the emergence of the automobile at the turn of the 20th century, with cheap fuel prices and lower manufacturing costs, North Americans became increasingly dependent on the automobile, allowing individual to travel faster and farther (Headicar 2013). However, vehicle travel is responsible for a number of costs to society. The most important social cost comes from urban traffic congestion (Parry and Small 2005), which was responsible for \$2.3 billion to \$3.7 billion of lost productivity in 2002 (Transport Canada 2006). Vehicle travel is also responsible for thousands of traffic fatalities and injuries; in 2013 alone, 1,923 Canadians died in motor vehicle accidents and 10,315 were seriously injured (Transport Canada 2015). Finally, car dependency has produced major environmental impacts, namely worsened air quality and greenhouse gas emissions. Vehicle emissions are responsible for over half of all smog production, including volatile organic compounds, nitrogen oxides, and particulate matter (U.S. EPA 2015). Each year in Canada, smog contributes to thousands of premature deaths, increased hospital and doctor visits, and lost productivity at school and work (Environment Canada 2014). Vehicle emissions from fuel combustion are also a significant driver of global climate change. In 2014, 23% of greenhouse gases in Canada came from the transportation sector (Environment and Climate Change Canada 2014), almost half of which were from private vehicles alone (Environment Canada 2011). The International Energy Agency (2015) projects that nearly half of the increase in energy-related emissions in the next 15 years will come from the transport sector. Together, these externalities cost billions of dollars to the Canadian economy. For instance, Jakob et al. (2006) estimated that the externalities associated with public and private transportation costs 2.23% of the GDP of Auckland, New Zealand each year. In Canada, the population and landmass, and thus subsequent vehicle use, is much greater. Consequently,

international, national and local governments all recognize the need to reduce the externalities of vehicle use (IPCC 2014; Environment Canada 2013a).

Trends in Car Use

In most developed countries since World War II, with suburbanisation and a burgeoning middle class, the proportion of cars on the road relative to population had been increasing (Millard-Ball and Schipper 2011). This trend is often viewed as a function of income, where people shift to faster, more reliable forms of transportation, albeit more energy-intensive, as their income and national GDP increase (Dargay et al. 2007; IPCC 2014). This was the trend in almost all OECD countries (Dargay et al. 2007), and by 2007, 90% of trips in the United States were taken in automobiles (IPCC 2007). Yet there is growing evidence that the trends of continuously growing car use, and its strong coupling to GDP, are changing.

Declines in car use, as measured by vehicle kilometres travelled, were first documented by the Brookings Institute in 2008 (Puentes and Tomer 2008), and within the last seven years, this emerging trend of plateauing or declining car use, sometimes called “peak car,” has become well documented (Newman and Kenworthy 2011; Goodwin 2012A; Goodwin and Van Dender 2013). The Brookings Institute found that in the United States, people have been driving less each year since 2007, both in urban and rural areas (Puentes and Tomer 2008). Not only has vehicle kilometres decreased, but driver’s licenses issued, number of trips taken, and new vehicles sold has also declined (Puentes 2012), while public transit use is on the rise and is at its highest since 1957 (Puentes and Tomer 2008). From 1995 to 2005, car use in Los Angeles and San Francisco declined by 2% and 4.8%, respectively, and Atlanta and Houston experienced larger declines of 10.1% and 15.2%, respectively (Newman and Kenworthy 2011).

This marked and unprecedented change in driving habits is not limited to the United States however; it has also been documented in Australia, the United Kingdom, and continental Europe

(Millard-Ball and Schipper 2011; Metz 2010; Newman and Kenworthy 2011; Kuhnimhof et al. 2013). Among eight OECD countries, vehicle ownership, vehicles use, and overall travel demand was steadily increasing from the 1970s until the early 2000s (Millard-Ball and Schipper 2011). Around 2004, car ownership started to rise much more slowly, while travel demand and vehicle use declined relative to GDP (Millard-Ball and Schipper 2011). In the five most populous cities of Australia, Sydney, Melbourne, Brisbane, Adelaide, and Perth, per capita car use peaked in 2004, and has since been decreasing (Stanley and Barrett 2010). In the United Kingdom, overall car use has continued to increase with population, yet per capita car use has stabilized (Metz 2010). Metz (2010) found that from 1972 to 2009, household travel expenditure, purpose of trips, frequency, and travel time all remained stable, while the average distance travelled was steadily increasing for 30 years until it plateaued around 2002.

Although it is not possible to tell how this trend will unfold in the future, Goodwin (2012B) proposed three possible projections of travel demand. Car use could either rebound and grow once the economy has improved, continue decreasing, or could stabilize and remain at its current level (Goodwin 2012B). Although it is not possible to predict the future, understanding the various factors influencing vehicle demand will help make decisions in the future in terms of transportation planning and climate mitigation.

Possible Explanations of Observed Trends

Economic factors such as GDP have been proposed to explain peak driving trends, although there is substantial debate surrounding this explanation (Goodwin 2012A; Goodwin and Van Dender 2013). The historical link between income and car use has been well established (Goodwin and Van Dender 2013), however in the U.K. and U.S., they began to decouple in the last decade (U.S. Energy Information Administration (EIA) 2014; Metz 2012; Metz 2013; Le Vine et al. 2009). For instance, until the 1990s,

average distance travelled increased in tandem with real household incomes in the U.K. until the late 1990s, after which incomes continued to rise while kilometres travelled stabilized or even fell (Metz 2012). The relationship between income and vehicle use is less clear at higher incomes (Goodwin and Van Dender 2013). A study in England and Wales found that in recent years, car use has declined significantly among higher earning men, while lower income men were still increasing vehicle use consistent with historical trends (Goodwin 2012A). Likewise, the proportion of cars on the road in developing countries is still increasing (Dargay et al. 2007). In terms of overall GDP, the 2008 recession has also been proposed as possible explanations to the “peak car” phenomenon, however Australia, the U.K., and the U.S. all exhibited a decrease in driving behaviour during a period of relative prosperity before the 2008 global recession (Newman and Kenworthy 2011; Metz 2010; Puentes 2012; Le Vine et al. 2009).

The rise in gasoline and fuel prices globally, especially in Europe, has also been suggested as an explanation for declining vehicle kilometres travelled (Puentes 2012; EIA 2013). Recent research estimates the elasticities of vehicle distance travelled with respect to gas prices to be around -0.1 in the United States (Gillingham et al. 2015), though they appear to be slightly higher for new vehicles alone, at roughly -0.22 (Gillingham 2014). Elasticities in Canada are similar; Barla et al. (2009) estimated gas price elasticity of driving demand to be approximately -0.2 in the long run. Such low elasticities of demand should not have a very large impact on gasoline consumption and car use (Kayser 2008; Barla et al. 2009). Alternatively, Hughes et al. (2008) found that price elasticities of gas consumption have fallen since 1975 and were estimated to be at -0.034 and -0.077 during 2001 and 2006. Using elasticities of gas consumption of -0.034 and -0.077, Millard-Ball and Schipper (2011) estimated that in the U.S. with the 15% increase in fuel prices in 2008, there should have been a 1%

decline in gasoline consumption, based on estimated price elasticity of fuel. However, there was a 4.3% reduction in fuel consumption for private vehicles, suggesting that fuel prices cannot explain recent changes in driving behaviour fully (Millard-Ball and Schipper 2011). Other researchers also note that the levelling out of vehicle use occurred before the escalation of oil prices in 2002 (Puentes and Tomer 2008; Le Vine et al. 2009). Nonetheless, income, fuel prices, the costs of driving, and other economic factors all contribute to vehicle use, although to what extent is difficult to know (Puentes 2012; U.S. EIA 2013).

As the baby-boomers age, most developed countries, including Canada, are experiencing a rapidly growing senior population (Employment and Social Development Canada 2016A). The amount of driving is typically dependent on one's life stage; those who are participating in the workforce and commute tend to drive more (US EIA 2013; Dutzik and Baxandall 2013). Dutzik and Baxandall (2013) argue that the large growth in vehicle use in 1980s and 1990s was the result of baby boomers passing through their prime earning and child-rearing years, where they would be frequently commuting to work, driving their children, and typically living in more car-dependent neighbourhoods. However, baby boomers are rapidly exiting the labour force and retiring (Employment and Social Development Canada 2016A), a life stage that has historically driven less (Dutzik and Baxandall 2013). As well, as part of the "empty-nester syndrome", many older adults are leaving the suburbs and resettling in cities, where less driving is required (Newman and Kenworthy 2011). Although people are living longer, seniors may also self-limit driving by shortening trips or travelling less as a consequence of physical and mental impairments (Braitman and McCartt 2008), although there is debate as to whether disability is increasing or decreasing as life expectancies lengthen (Metz 2012). Newman and Kenworthy (2011), Millard-Ball and Schipper (2011), Metz (2012) and the US EIA (2013) suggest that since the share of seniors is rapidly

growing, and as old people should drive less, aging populations could be contributing to the decline in vehicle use.

However, Kuhnimhof et al. (2012) found the opposite in Germany, where older people are driving more than ever before, but the dramatic decline of car use in 18-29 year olds is overshadowing other age groups and shaping the national trend. Kuhnimhof et al. (2013) quantified the relative impact of both changing age structure and vehicle travel demand in France, Germany, Great Britain and the U.S. They found that although aging did play an important role in overall national trends, particularly after the turn of the century, changes in travel demand and shifts to different modes played a much more significant role (Kuhnimhof et al. (2013). In fact, young adults made the largest negative contribution to recent changes in per capita vehicle use (Kuhnimhof et al. 2013).

In previous generations, a driver's license was an important rite of passage into adulthood, especially for males, but today fewer young people are learning how to drive (Goodwin 2012A; Kuhnimhof et al. 2012). In fact, the licensing rate for young people in the U.S. and Great Britain has been in steady decline since the early 1990s (U.S. EIA 2014; Le Vine et al. 2009). In Germany, 18 to 29 year olds used to be the most car-oriented group, yet today they drive less than all other age groups (Kuhnimhof et al. 2012). In fact, Kuhnimhof et al. (2012) found that young men exhibited the largest decrease in car use, while young women's behaviour remained relatively stable, and Le Vine et al. (2009) found that gender differences in driving behaviour in Great Britain were disappearing. Kuhnimhof et al. (2012) found that in the last decade, young adults' ownership of, or access to, cars declined significantly for young people who have left their parents household, but car use remained unchanged for the young couples with children. Young adults, even those with access to a car, are now shifting to multiple modes of travel, particularly public transit (Kuhnimhof et al. 2012; Davis et al. 2012). Public transportation

among young adults nearly doubled from 1997 to 2006 in Germany (Kunhimhof et al. 2012), and ridership increased 32.3% in the United States from 1995 to 2011, double that of the population growth rate (Puentes 2012). However, multimodal travel behaviour depends on the availability of reliable and affordable alternative transportation (Puentes 2012), which is lacking in many parts of Canada and the United States. The decline in car use by young adults may be linked to economic factors, such as limited employment and debt (Kunhimhof et al. 2012; Puentes 2012). In a UK survey of non-licensed adults, young people were more likely to mention cost-related factors, while older people were more likely to cite reasons such as disinterest and physical limitations for not learning to drive (UK Department for Transport 2015). However, in the U.S., the decline in car use began before youth unemployment spiked in 2009 (Davis et al. 2012). Kunhimhof et al. (2012) suggest that the cost of driving, including fuel prices and the cost of car ownership increased substantially in the 1990s in Europe, while real-time incomes grew more slowly. The change in youth culture around cars may also be due to socioeconomic shifts in the population; more young adults are attending university and participating less in the workforce, while starting families later than their counterparts in previous generations (Kunhimhof et al. 2012).

Many researchers agree that the change in behaviour can be partly explained by re-urbanisation of large cities (Headicar 2013; Newman and Kenworthy 2011; Metz 2013; Goodwin and Van Dender 2013). This is particularly apparent for cities with available alternative modes, such as extensive public transportation or safe walking routes (Goodwin and Van Dender 2013). Headicar (2013) found that the difference in annual kilometres travelled between the most and least urbanized areas in England has been widening considerably since the 1980s, with the least urbanized areas now driving triple the distance as a result of land-use planning and settlement characteristics. For the last two decades, many American and Australian cities were seeing an urban renaissance (Newman and Kenworthy 2011), and

many cities in the U.K. have become much denser as the government adopts more policies to discourage greenfield development and sprawl (Headicar 2013; Goodwin and Van Dender 2013). Headicar (2013) suggests that the stagnation of per capita car use in England in the late 1990s and early 2000s coincided with a dramatic increase in the share of total population living in urbanized areas. Metz (2013) found that even as London's urban population, density, and income grows, per capita car use is decreasing. In Great Britain, the greatest decline in driving was in London and other major cities, while the rest of the country remained relatively level in their vehicle use (Le Vine et al. 2009). However, per capita vehicle use in rural areas in the United States has also been decreasing since 2006 (Puentes and Tomer 2008).

Newman and Kenworthy (2011) and Puentes (2012) propose that cities may be hitting a "Marchetti Wall," whereby people do not want to travel more than 1.1 hours a day. With increasingly large cities, vehicle commute times could easily exceed 1.1 hours, subsequently encouraging individuals to migrate to denser areas with shorter, but perhaps slower, commute times. For example, the commuting trip speeds are lower in denser, less car-oriented cities, compared to lower density cities, while travel time itself is relatively stable (Kenworthy and Laube 1999). This is consistent with other research (Millard-Ball and Schipper 2011; Metz 2010), which found that although vehicle use is declining, the travel time among all modes has remained at around 1.1 hours a day.

Alternatively, Metz (2013) proposed that travel demand has been saturated, as individuals have a diminishing marginal utility for the additional access and choice the automobile can provide. As more options and choice increase with greater urban and suburban development, travel to farther distances via car is no longer necessary, saturating the demand (Metz 2013). Goodwin (2012B) found that only a quarter of the decline in car trips in the UK from 1999 to 2009 could be explained by modal substitutions, while the rest was the result of shortened journeys. In addition, many cities are now attempting to

promote more pedestrianized downtowns, with traffic calming and less parking, and encouraging more multimodal behaviour, which may be affecting people's driving behaviour (Kuhnimhof et al. 2012).

It has also been suggested that technology is replacing the need for vehicle travel (Goodwin 2012A; Metz 2013; Puentes 2012). For instance, people could be travelling less in exchange for more tele-commuting and e-commerce. However, to date there is little conclusive evidence on the role of technology influencing travel behaviour (Kuhnimhof et al. 2012; Goodwin and Van Dender 2013)

Changes in driving patterns are not likely due to one single factor, but the convergence of multiple factors (Goodwin and Van Dender 2013; Newman and Kenworthy 2011; Puentes 2012). The heterogeneity in driving patterns within developed countries is likely the result of urban and transport policies, personal preference, and financial constraints (Goodwin and Van Dender 2013). Goodwin and Van Dender (2013) suggest that changes in car use was first fueled by economic forces, but was then propagated by other factor such as public transit investments, policies to restrict traffic and parking, gradual immigration to denser urban areas, advancements in information technology, and changing attitudes towards the car. For instance, average real incomes have rebounded since the 2000s, however car ownership and use has not followed suit, perhaps due to changing habits and attitudes (Goodwin and Van Dender 2013). Regardless, little research has been conducted on how these economic, demographic, and social factors compare in terms of relative influence on driving behaviour.

Although it is impossible to predict future trends in transportation, understanding the possible drivers behind aggregate trends can help produce more accurate forecasts and considerations for the future (Goodwin 2012; Goodwin and Van Dender 2013). This could include infrastructure investment, land-use planning, emissions accounting, and energy and fuel consumption modelling.

Canadian Landscape

Canada has the highest population growth rate (0.9%) among all G7 countries, with immigration accounting for two thirds of the growth (Statistics Canada 2015.) Ontario, Quebec, British Columbia and Alberta make up 86.3% of Canada's population (Statistics Canada 2015). Seniors make up the fastest-growing age group in Canada, due to the lower fertility rate of young adults, longer life expectancies, and the aging baby boomers (Employment and Social Development Canada 2016A). In 2011, there were 5 million seniors in Canada, and by 2051, one in four Canadians is expected to be over 65 (Employment and Social Development Canada 2016A). Currently, seniors in the Maritimes, Quebec, Ontario, and British Columbia outnumber children aged 0 to 14, while the opposite is true in the Prairie Provinces (Statistics Canada 2015). As discussed previously, this rapidly growing share of seniors are not typically part of the workforce and thus do not commute, tending to drive less than individuals in other life stages (US EIA 2013; Dutzik and Baxandall 2013).

The proportion of Canadians living in urban centres, now at 81%, has been on the rise since Confederation, with one third of all Canadians now living in Toronto, Vancouver and Montreal (Employment and Social Development Canada 2016B). In 2011, Ontario, British Columbia and Alberta had a larger proportion of their population living in urban areas than the national average, while Manitoba and Prince Edward Island had significantly more rural dwellers than the average (Employment and Social Development Canada 2016B). Finally, the income gap between generations is widening in Canada, with greater inequality between young and older Canadians now, compared to 30 years ago (Gill et al. 2014). Although these factors all influence driving behaviour in Canada, to date there has been almost no research on peak driving trends in Canada.

Research Questions

1. In the last 25 years, did vehicle kilometres travelled in Canada reach a peak or plateau in the early 2000s?
2. How do patterns in vehicle use compare between provinces and between Canada and the United States?
3. If there is a change in car use, what are the probable causes? For instance, is it the result of an aging population, less overall activity by young adults, lower licensing rates, economic influences, or other factors?

Hypotheses

1. In the United Kingdom, the United States, Australia, Germany, and other OECD countries, vehicle kilometres travelled plateaued or began to decline in the early 2000s. Given Canada's cultural, social, and economic similarities, we expect to see a trend in Canada consistent with the United States and Australia, with decreasing vehicle kilometres travelled beginning around 2004.
2. We expect that all provinces will have declining or plateauing per capita car use, although provinces with greater urban population and public transit, such as Ontario or British Columbia, will have a more prominent change compared to more rural provinces with less alternative transit options such as Manitoba. Canada and the United States should have similar patterns, and relatively equal contributions of influencing factors.
3. Although an aging population, less overall activity by young adults, lower licensing rates, and economic influences likely all play a role in influencing driving habits, declining activity by young adults probably has the greatest impact on driving behaviour, through modal shifts and lower licensing rates.

METHODOLOGY & DATA

Decomposition Analysis

Canadian vehicle kilometres travelled (VKT) were examined from 1990 to 2013 to assess if car use has been following similar patterns to other OECD countries, whereby per capita driving increased steadily until the late 1990s or early 2000s, followed by a plateau or decline. Canadian vehicle use was compared to American patterns, and within Canada, comparisons were conducted between all ten provinces. VKT were combined for British Columbia and the territories.

An index decomposition analysis (IDA) was used to decompose trends in driving, in order to determine what has been responsible for changes in VKT. Index decomposition analysis is frequently used to deconstruct energy consumption or greenhouse gas (GHG) emissions within an industry, as it allows one to determine what is responsible for changes in energy use or emissions (Ang 2004). As an illustrative example, imagine that GHGs from energy production are declining in the province of Alberta. There are a few possible explanations; it could be due to less overall energy being demanded, it could be the result of a shift away from coal towards lower carbon energy sources, or it could be because power plants are becoming cleaner and more efficient. Alternatively, it could be a combination; economic development could be growing and subsequently demanding more energy, but the energy sector itself could be releasing fewer GHGs as Alberta moves away from coal. This relationship can be quantified using the following equation;

$$GHG = \sum_i A \frac{A_i E_i}{A A_i} \quad (1)$$

where A is the total activity level of all production sources, A_i is the activity level of each production source i , and E_i is the emissions for each production source i . This can be simplified to;

$$GHG = A \sum_i S_i I_i \quad (2)$$

where A is to the total activity of energy production, S_i is the structure of production sources (how much energy is from coal, nuclear, etc.), and I_i is the emission intensity of production source i . An IDA allows one to quantify each of these factors and determine how they are contributing to the overall trend in GHGs, or any other variable of interest.

IDAs have not often been applied to personal vehicle travel, although some examples do exist. Millard-Ball and Schipper (2011) successfully applied an IDA to analyze the energy intensity of motorised travel, including vehicle and air travel, for eight high-income countries over the last forty years. They found that before 2004, increased energy use in the transport sector was mostly due to increases in personal travel demand, although this was counterbalanced slightly by improved energy efficiency (Millard-Ball and Schipper 2011). Most notably, the authors found that total motorised passenger travel peaked in 2004; they suggested that if energy efficiency continues to improve, and individuals shift back towards trains and buses somewhat, emissions from personal travel could be lower than they were in 2011 by 2020 or 2030 (Millard-Ball and Schipper 2011). Using a more similar method to ours, Kuhnimhof et al. (2013) used an IDA to assess the relative impacts of demographic changes, overall travel demand, and personal vehicle use in the United States, France, Germany, and Great Britain. They determined that in France and the U.S., recent changes in VKT were due to declines in all travel modes, while in Germany and Great Britain, modal shifts away from cars also played a significant role (Kuhnimhof et al. 2013).

In this case, we applied an IDA to assess yearly changes in VKT and its component parts: population growth, changing age structure of the population, licensing rates, and total distance driven per driver. The data was not available to conduct a province-by-province comparison of disaggregate trends in vehicle use, so Canadian patterns were instead compared to American vehicle travel. Using

mathematical equations outlined in Ang (2005), the IDA allowed us to weigh the relative contribution of each factor and determine what is responsible for overall trends in VKT. The governing function for the IDA is as follows,

$$VKT = P \sum_a \frac{P_a}{P} \frac{DL_a}{P_a} \frac{VKT_a}{DL_a} \quad (3)$$

where VKT is vehicle kilometres travelled, P is population, a is age group, and DL is the number of licensed drivers. More specifically, P towards the left represents population growth, $\frac{P_a}{P}$ measures age structure of the population over time, $\frac{DL_a}{P_a}$ represents licensing rates for each age group over time, and finally, changes in total distance driven per driver is measured as $\frac{VKT_a}{DL_a}$. Using the mathematical formulations described by Ang (2005), the aggregate trend and relative contribution of each of these factors was quantified and compared. Drivers were categorized into four age groups: under 24, 25 to 44, 45 to 64, and over 65. For Canadian trends, the IDA was completed for every year between 2000 and 2009, except for 2001 due to data limitations, as discussed below. A period-wise IDA was completed for the United States, from 1995 to 2001, and from 2001 to 2009. The available data from the United States did not support a yearly decomposition.

An IDA has certain implicit assumptions; it assumes that if there is a change in one of the component factors, the aggregate variable will change proportionally. This is a limitation to the method, as the component and aggregate variables are not necessarily proportionally related, and the relationship may be much more complex. Nonetheless, it is still a useful and powerful method to understand vehicle use.

Multiple methods exist to conduct decomposition analyses, such as Laspeyres method or Fisher Ideal, however some are better than others (Ang 2004; IEA 2013). A logarithmic division mean index

(LDMI) was used for our IDA, for a number of reasons. Most importantly, the LDMI approach produces perfect decomposition, meaning that there are no unexplained residual terms in the results (Ang 2004). LDMI is also adaptable, it can be applied to time-series data without having to change the mathematical formula for decomposition (Ang 2004). As well, the decomposition formula remains the same regardless of how many factors are being quantified (Ang 2004). The LMDI method can also be conducted multiplicatively or additively; the former decomposes the “ratio” of change of the aggregate variable, while the latter decomposes the “difference” of change (Ang 2004). This provides LDMI with a methodological advantage, as one can use it regardless of their preferred type of assessment (Ang 2004). Finally, the LMDI approach is straightforward to conduct, and results can be easily interpreted, in part because there are no unexplained residual terms (Ang 2004). For these reasons, the LDMI approach is the most preferred (Ang 2004; IEA 2013).

Regression Analyses

A formal IDA quantifies the relative contribution of various factors to explain changes in an aggregate trend, in this case changes in VKT over time. Unfortunately, IDAs are quite data intensive and require all variables to fit into a mathematically sound equation. As a result, the IDA could not include other variables, such as income, which may also be affecting VKT. For instance, the IDA may suggest that the variable with the most influence on VKT is distance travelled per driver, indicating that the change is behavioural. However, if the IDA is followed by a regression analysis, one might be able to determine what other aspects are affecting this shift in behaviour, such as rising gas prices. Multiple regressions allow one to examine a battery of other variables which would not be able to fit into the IDA, as IDAs are limited by mathematical rules. By including other variables, we can examine more thoroughly what may be responsible for changing VKT.

Furthermore, IDAs have a specific set of assumptions; if there is a change in one of the component factors, the IDA assumes that the aggregate variable changes proportionally. In reality however, this may not necessarily be true, and the relationship may be much more complicated. Various variables may interact to produce a different outcome. A multiple regression is much more flexible, and can predict VKT in a dynamic, complex environment. Specifically, one can use a multiple regression analysis to estimate whether certain variables are statistically related to VKT, determine whether this relationship is positive or negative, and estimate the strength of the relationship.

The regression analysis, which is limited to Canada, will determine how these variables are related to the dependent variable, per capita VKT. Our variables of interest in the regression are gas prices, income, the age structure of the population, and the share of people living in urban areas. Even though age structure is included in the IDA, it is important that it also included in the regression model, so as to avoid biased results. In a regression, when one omits a variable that is correlated with the independent variable and at least one dependent variable, the model will overestimate or underestimate the relationship for other variables. By including age structure in the regression, we can avoid this type of bias in the results. Furthermore, including some of the same variables in both the IDA and the regression analysis produces more robust results, as each method has its own strengths and weaknesses.

As mentioned above, results can be biased when variables are omitted which are correlated with the independent variable and at least one dependent variable. Unfortunately, some types of variables cannot be observed or measured. These might include factors which differ between provinces, but are held constant over time, such as geography. For instance, British Columbia's mountain ranges might require more roundabout routes and thus greater driving distances. There are also variables which

change over time but do not vary between provinces, such as fuel efficiency of vehicles. Although this type of data does not exist for the purposes of the regression analysis, we still want to control for their effect. Conveniently, a fixed-effects regression analysis can control for these unobserved, unmeasurable variables, using a large set of panel data. Panel data, also known as cross-sectional time series data, is data which is observed over time and between entities, in this case provinces. By using fixed-effect regression analyses, which controls for the effects of variables that vary both over time and between provinces, we can estimate the effect of the dependent variables on per capita VKT more accurately.

Coefficients were estimated using four variations of the same model: a pooled data regression, province-fixed effects, time-fixed effects, and both province- and time-fixed effects regression. The province-fixed effects model controls for omitted variables that vary between provinces, such as geography, but are constant over time. On the other hand, the time-fixed effects model controls for factors that change over time but are steady between provinces, such as improvements in fuel efficiency. The pooled data regression, or a standard linear multiple regression, does not use time-fixed or province-fixed effects, but was included for comparison. The final model variation uses both province- and time-fixed effects, thus providing the most robust estimates, as it controls for unmeasured factors that vary both over time and between provinces. The relationships between the dependent variable, per capita VKT, and the independent variables were estimated using the follow fixed-effects specification:

$$\begin{aligned} \log(\text{percapitaVKT})_{tp} = & \beta_0 + \\ & \beta_1 \log(\text{gasprice})_{tp} + \beta_2 \log(\text{income})_{tp} + \beta_3 (\text{urbanshare})_{tp} + \beta_4 (\text{share aged } 18 - 24)_{tp} + \\ & \beta_4 (\text{share aged } 65 +)_{tp} + \delta_t + \lambda_p + \varepsilon_{tp}. \end{aligned} \quad (4)$$

*Per capita VKT*_{tp} is per capita vehicle kilometres travelled for year *t* and province *p*, gas price is measured as the price index relative to 2002, and income is measured as the median income, both of which have

been controlled for inflation. Urban share is the proportion of those living in urban centres, and shares of age groups include those between the ages of 18 and 24, and over 65. Other age groups were omitted to avoid multicollinearity. Fixed-effects for time and provinces are represented as δ_t and λ_p , respectively, while ε_{tp} represents the error term for factors not captured in the model. Logs of VKT, gas price, and income were used to interpret regression coefficients with more ease, so the change in dependent and independent variables could be understood in terms of percentages. Logs were not required for the urban or age group shares, as these are already presented as percentages.

Certain assumptions must also be met in order to trust results from a regression analysis. These are: (a) linear relationships between the dependent and independent variables, (b) normally distributed residuals, (c) equal variance of residuals across the range of the independent variable, and (d) independence of residuals. The assumption of a linear relationship was not met perfectly for median income (Appendix 1). Attempts were made to transform median income so a linear model could properly predict the relationship, but they were unsuccessful. The entire data set also had more outliers than desired (Appendix 2), but they could not be removed. All other assumptions were met and are outlined in Appendix 3.

Although this method is widely used, those interpreting results of a multiple regression analysis must be cautious. First of all, missing variables can bias the results. Certain variables have been controlled for in the fixed-effects model, such as variables that vary between provinces but are steady over time, or variables that are constant between provinces but change over time. However, some variables are still not controlled for, such as those which change over time *and* within provinces. For instance, some provinces may have been investing in smart transportation and better urban design, or British Columbia may be experienced a cultural shift away from car dependency, in part due to the recent

carbon tax. These factors may affect vehicle use, but they are not controlled for in the fixed-effects regression. As well, snow and weather events, or even local policies which impact driving, were not included, as this data did not exist. As a result, outputs from the regression may be slightly biased. A second key concern is that regression analyses cannot necessarily explain whether one factor *causes* a change in the other, only that they are related. For instance, the regression could suggest that VKT and the percentage of people living in urban areas is strongly related. However, it does not tell us whether people are driving less as they move into cities, or if people are moving into cities because they do not want to rely on car travel. This issue can often be surpassed with good experimental design, which allows one to establish cause-and-effect relationships.

The regression results estimate how two variables are related, when all other variables are held constant. In reality however, the variables are changing independently of one another. We want to know what is responsible for changes in VKT, in a dynamic situation where multiple variables are changing. Using estimates from the regression analysis, counterfactual scenarios were simulated in order to determine what amount of change in VKT was due to changes in certain variables. Specifically, three counterfactual scenarios were estimated; one in which gas prices were fixed at their 1999 level (Figure 1), one in which income was fixed at its 1999 level (Figure 2), and one in which the proportion of age groups was fixed to 1990 proportions (Figure 3).

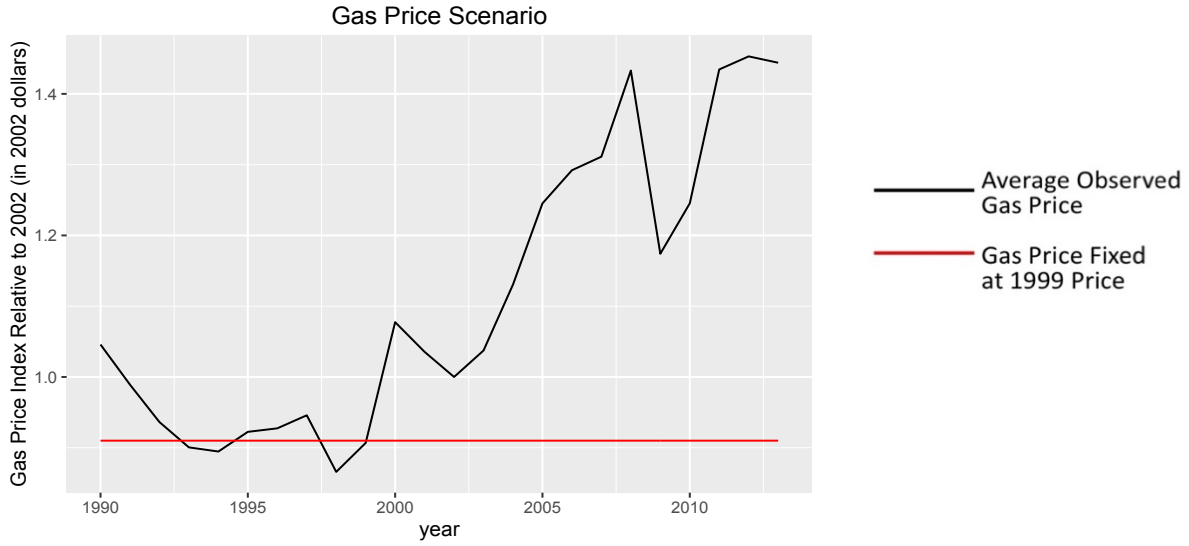


Figure 1. Gas prices, for the counterfactual scenario in which gas prices are fixed at the 1999 price, and for observed conditions, averaged across all ten provinces.

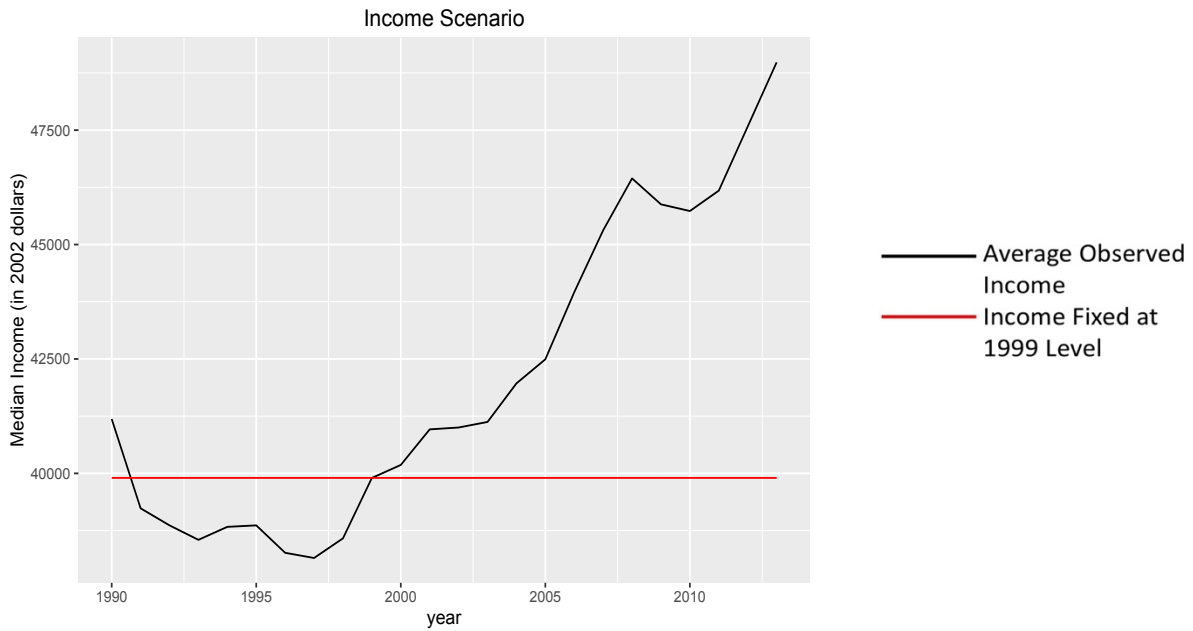


Figure 2. Median income, for the counterfactual scenario in which income is fixed at its 1999 level, and for observed conditions, averaged across all ten provinces.

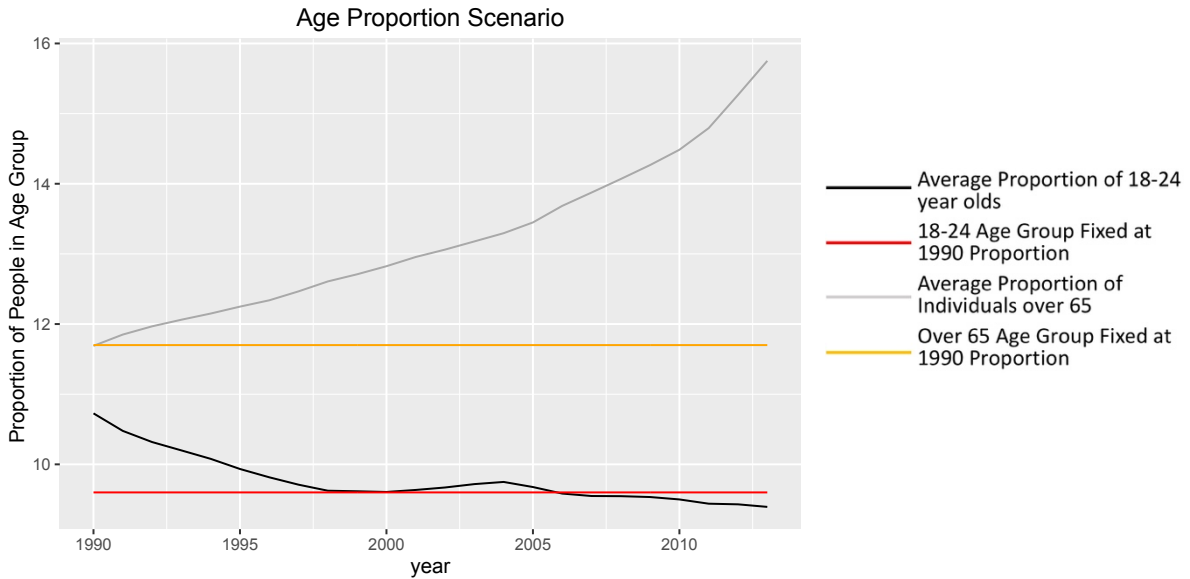


Figure 3. Proportions of age groups, for the counterfactual scenario in which age groups are fixed at their 1990 proportions (red and orange), and for observed conditions (black and grey), averaged across all ten provinces.

For each of these scenarios, the other variables behaved normally and followed their real life trajectories, allowing us to estimate what amount of change in VKT was due to gas prices, income, and shifts in demographics. In many countries, the “peak” in vehicle use occurred around 2004, but to account for a lag in behaviour, gas prices and income in the counterfactual scenarios were fixed in 1999, and averaged across all ten provinces. It was also around the late 1990s when gas prices and income began steadily increasing (Figure 1; Figure 2). Because age proportions were increasing steadily throughout the period from 1990 to 2013, the age groups are fixed in 1990, rather than 1999 (Figure 3).

The regression with both time- and province-fixed effects was employed to estimate the counterfactual scenarios for gas price and age groups. However, the effect of median income was not significant for the regression with both province- and time-fixed effects, so the time-fixed effects model was used instead.

Data Sources

Multiple sources of data have been compiled for the analyses. In Canada, the Office of Energy Efficiency at the Ministry of Natural Resources Canada provides aggregate-level data on vehicle kilometers travelled from 1990 to 2013 for each province. In the United States, this information is provided by the Office of Highway Policy Information at the U.S. Department of Transportation. Only cars and light trucks (less than 4.5 tonnes) were considered in the analysis. Vehicle kilometres travelled were then calculated on a per capita basis. In Canada, population estimates were provided by Statistics Canada on a yearly basis from 1990 to 2013. In the U.S., national population estimates came from the U.S. Census Bureau.

The Canadian Vehicle Study surveyed Canadian households from 2000 to 2009 using diary entries to track vehicle travel, including distance travelled by driver age group. Data from 2001 is too unreliable for the purposes of the IDA, and missing data for drivers aged 16 to 20 was imputed for 2004, 2005, and 2006. Although it would have been fruitful to decompose travel trends over a longer period of time, the statistical methods of two other available Canadian travel surveys differed in such a way that comparison across surveys was not possible.

Data on American vehicle use was collected from the comprehensive and data-rich National Household Travel Survey, available for 2001 and 2009, and the 1995 National Personal Transportation Survey, both from the Federal Highway Administration at the U.S. Department of Transportation. Both surveys are designed to be compared over years and between surveys, and employ similar methods of household diary entries to track travel behaviour (U.S. Department of Transportation 2009). They include data on age groups of drivers, and vehicle kilometres travelled per driver.

In Canada, number of licensed drivers per age group is only available at the provincial level. Data was provided by provincial licensing agencies and transportation ministries in Quebec, Manitoba, Ontario, Alberta, Saskatchewan, and New Brunswick, which were used to impute licenses at the national level. In the U.S., the Office of Highway Policy Information provides national data on licensed drivers.

Panel level data for the regression analyses came from Statistics Canada and Natural Resources Canada. Specifically, vehicle kilometres travelled from 1990 to 2013 were provided by Natural Resources Canada, while population estimates, gas price indices and median income levels were provided by Statistics Canada, between 1990 and 2013. Inflation was controlled using 2002 real dollar terms for gas price consumer index and median incomes. All data was available on an annual basis except for the percentage of the population living in urban areas, which is collected every five years as part of the census. Accordingly, intercensal data on urban populations was linearly estimated.

Vehicle kilometres travelled for British Columbia and the three territories were combined, while other variables, such as income and gas prices, were not. Although this could bias the estimates, the effect should likely be small, as the share of driving in Canada's territories is limited in comparison to provinces, especially given the long winters, small population, and the many towns without road access.

RESULTS

Decomposition of Vehicle Use in Canada & the United States

Overall Travel Demand

As discussed elsewhere (Newman and Kenworthy 2011; Kuhnimhof et al. 2012; Millard-Ball and Schipper 2011), American per capita VKT was rising steadily for decades until the early 2000s, when it unprecedentedly plateaued and began to decline (Figure 4). Since then, there has been a slight upturn in vehicle use in the United States in 2014 and 2015, which may or may not indicate a recovery in the growth of vehicle use.

Per capita, Canadians drive far less than Americans. In 2013, Canadians drove just a fraction of what Americans drove, approximately equal American vehicle distance in 1970 (Figure 4). More importantly, the pattern of declining or plateauing vehicle use is much more muted in Canada compared to the U.S. (Figure 4).

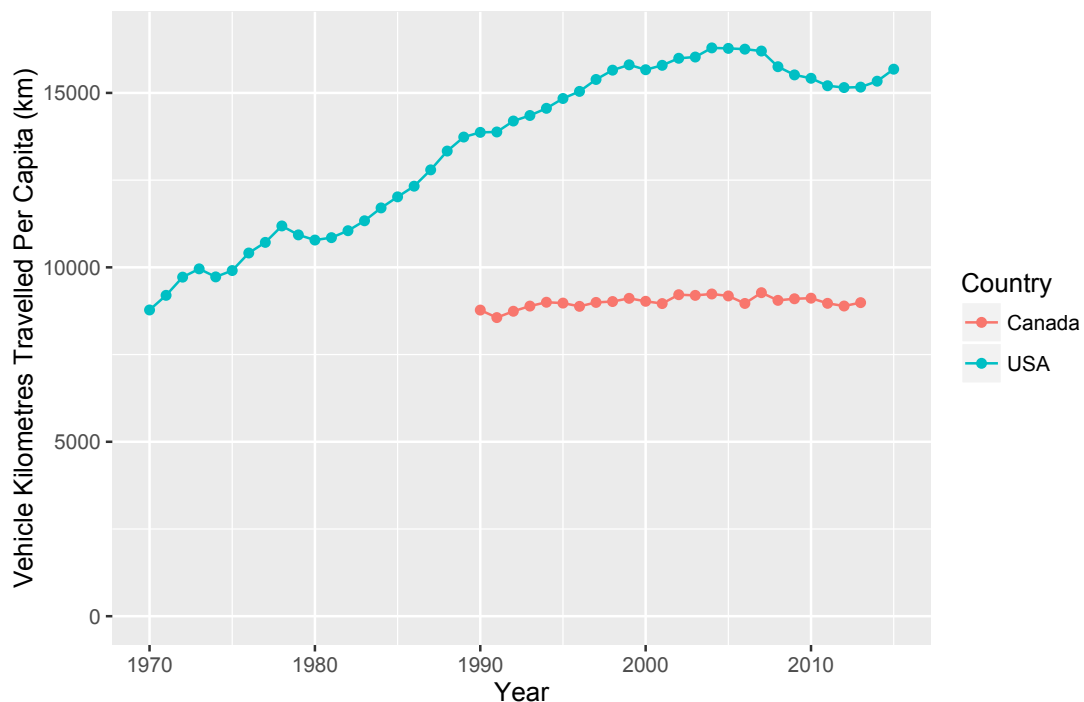


Figure 4. Per capita vehicle kilometres travelled in Canada from 1990 to 2013 and in the United States from 1970 to 2015.

This is far different from the patterns exhibited in other developed countries, such as the U.K. and Germany, which saw an unprecedented change in per capita vehicle use at the turn of the millennia (Metz 2010; Headicar 2013; Kuhnimhof et al. 2012; Newman and Kenworthy 2011). What may be more striking however, is the lack of extreme growth in vehicle use in Canada in the 1990s and earlier, demonstrated in the United States.

In isolation, it does appear that Canada may have experienced a modest peak in per capita vehicle use in the early 2000s (Figure 5). This pattern is quite variable, and without longer term data, it is difficult to understand trends in Canadian vehicle use fully.

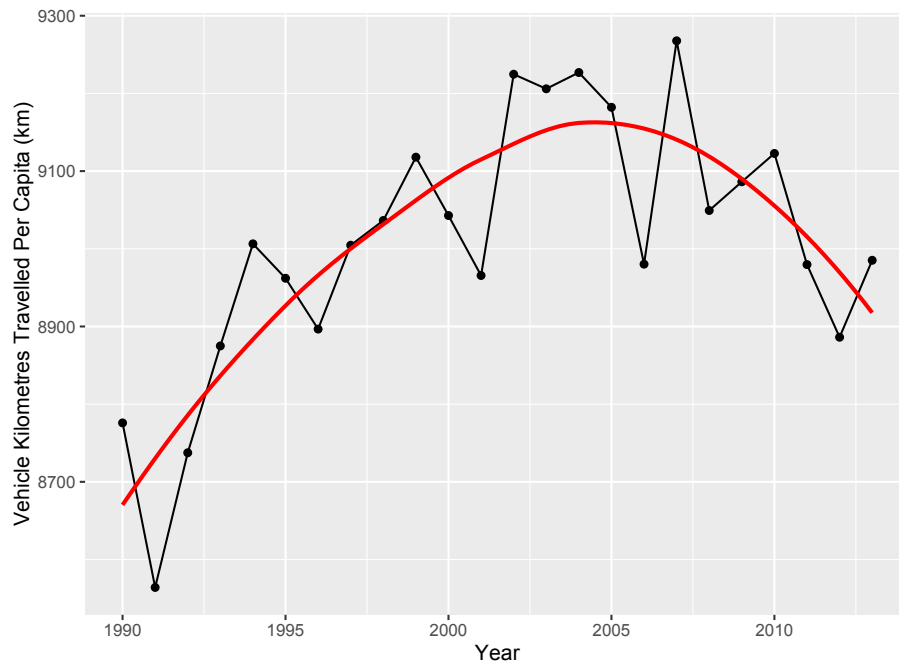


Figure 5. Per capita vehicle kilometres travelled in Canada from 1990 to 2013. The trend line is represented in red.

Although it is difficult to draw conclusions from the overall national trend in Canada, it is noteworthy that patterns differ substantially between provinces (Figure 6). Some of the variation in

vehicle kilometres travelled at the national level could be the result of different, or even diverging, patterns at the provincial level.

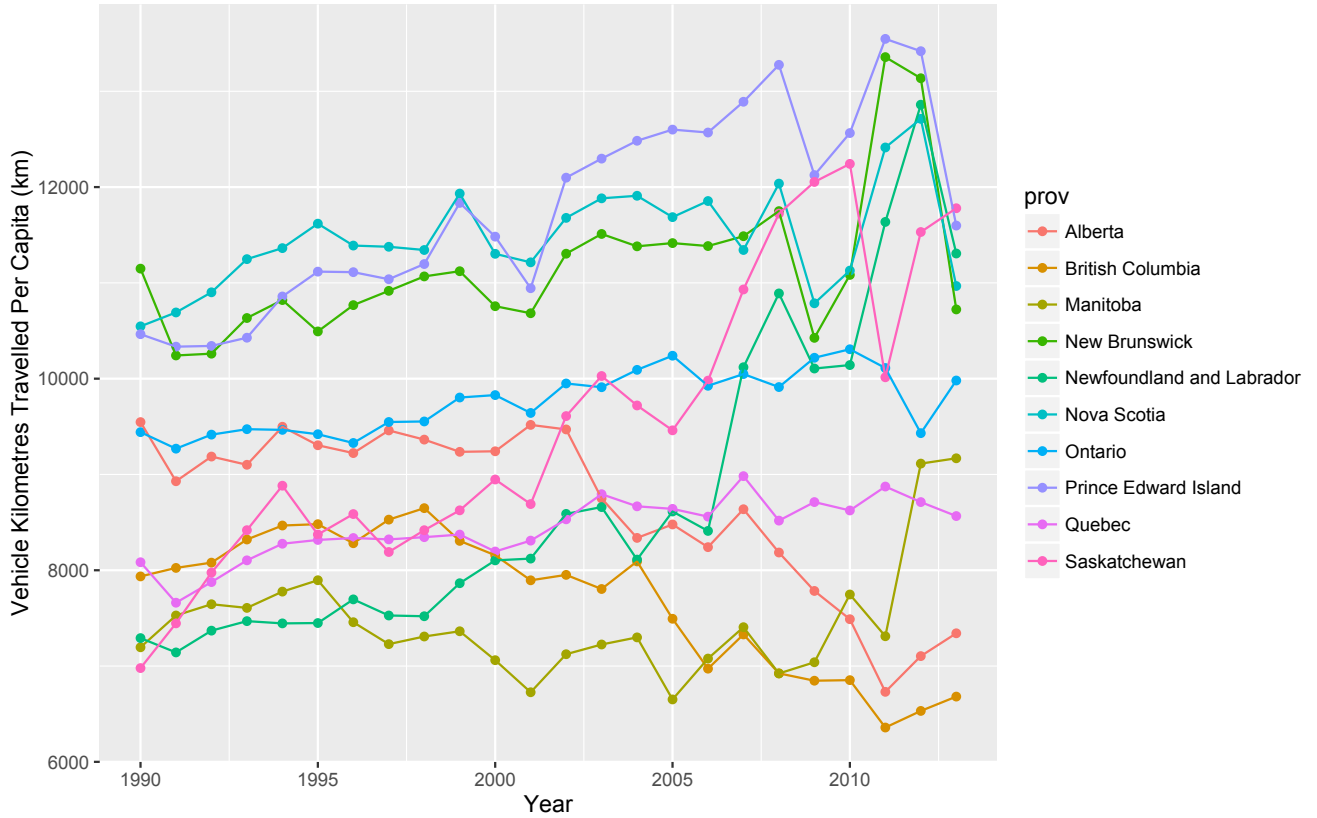


Figure 6. Per capita vehicle kilometres travelled for each province, from 1990 to 2013. British Columbia and the territories are combined.

For instance, British Columbia and Alberta show a clear decline starting in the late 1990s, while Prince Edward Island, Saskatchewan, Newfoundland, and to some extent Manitoba, show the opposite. Alternatively, per capita vehicle use in Nova Scotia, Ontario, and Quebec appears to have plateaued, if not in the 1990s than in the early 2000s. Data was not readily accessible to conduct a similar state-by-state comparison for the U.S.

Decomposition Analysis: United States

Trends in American vehicle use are decomposed in Figure 7, from 1995 to 2009.

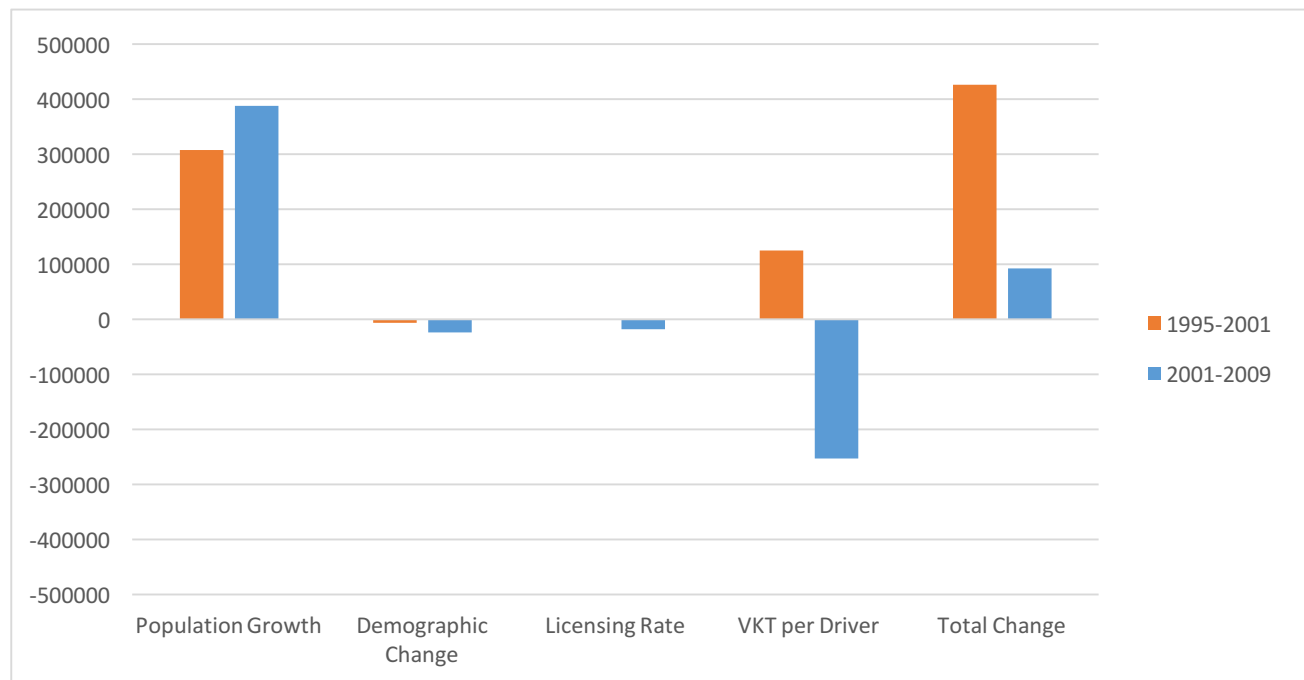


Figure 7. American vehicle trends decomposed from 1995 to 2009, demonstrating the relative contributions of population growth, changes in age structure, changes in the proportion of licensed drivers, and the distance driven per licensed driver, as well as the total change in VKT.

In both periods, total VKT was increasing, although to a much lesser extent in 2001-2009 (Figure 7). During the 1995-2001 period, individual car use, measured as VKT per driver, was growing (Figure 7). This is consistent with overall trends of per capita car use seen in the United States (Figure 4). The largest contributing factor to increasing VKT from 1995-2001 was population growth, which was exerting a strong, positive influence (Figure 7). Conversely, between 2001 and 2009, total VKT was still increasing, but to a much lesser extent, while distance driven per driver was decreasing (Figure 7). Between 2001 and 2009, for the first time in decades, American drivers drove less, representing the unprecedented change in vehicle use described in Figure 4. This is consistent with other research, which found a turn-

around in personal vehicle use beginning in the early 2000s (Puentes and Tomer 2008; Kuhnimhof et al. 2008). Like the first period, population growth was exerting a strong, positive influence on VKT, offsetting the decline in individual driving (Figure 7). One could infer that population growth was likely a contributing factor to the strong growth in personal vehicle use seen in the 1990s and earlier. During both periods, licensing rates had little to no effect, as did demographic changes (Figure 7), even though baby boomers began reaching retirement during the second period.

Decomposition Analysis: Canada

In Canada, the decomposition of vehicle use appears to be quite similar to the United States. However, because trends could only be analysed for a much shorter period, changes in vehicle use are much less clear. Nonetheless, yearly (Figure 8) and period-wise (Figure 9) decomposed trends still shed light on vehicle use in Canada.

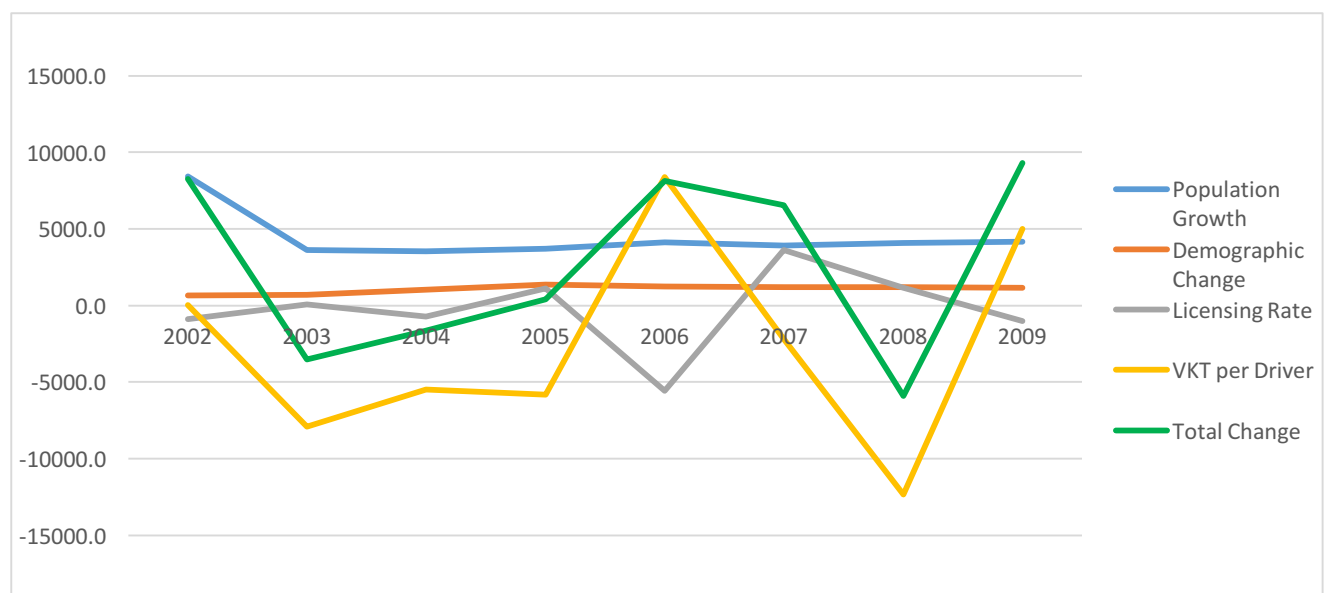


Figure 8. Canadian vehicle trends decomposed on a year-to-year basis from 2000 to 2009 (omitting 2001), demonstrating the relative contributions of population growth, changes in age structure, changes in the proportion of licensed drivers, and the distance driven per licensed driver, as well as the total change in VKT.

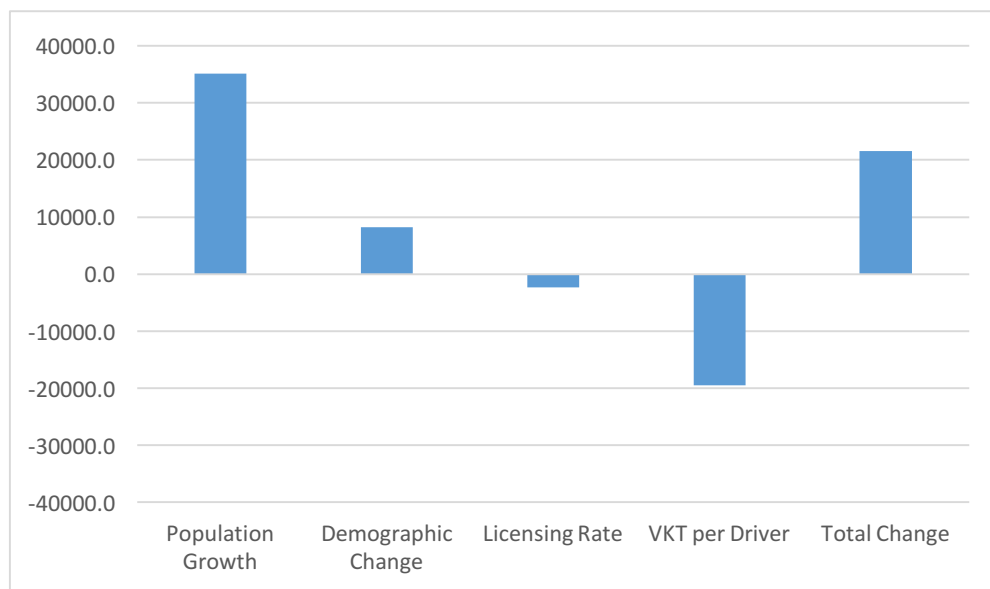


Figure 8. Canadian vehicle trends decomposed for the period of 2000 to 2009, demonstrating the relative contributions of population growth, changes in age structure, changes in the proportion of licensed drivers, and the distance driven per licensed driver, as well as the total change in VKT.

Like the U.S., population growth was having a positive influence on overall vehicle use in Canada, while the effect of demographic change was very minimal (Figure 8; Figure 9). Changes in licensing rates, though more variable over the period, still appear to have a small effect overall (Figure 8; Figure 9). On a year-to-year basis, individual car use, measured as VKT per driver, has a much more ambiguous pattern, fluctuating between growth and decline over the period of 2000 to 2009 (Figure 8). VKT per driver was having a notable negative influence on overall VKT until 2006, when individual vehicle use increased (Figure 8). It then fell again, but rebounded soon afterwards. Because American trends cannot be decomposed on a year to year basis, we cannot determine whether this variability was also the case for the U.S. In addition, the variability seen in Canadian VKT per driver may be reflective of the fact that per capita vehicle use did not change as dramatically during this period (Figure 4), unlike the U.S., which saw a clear period of growth followed by a clear plateau or even decline. However, when a period-wise decomposition is conducted for Canada, the trend is much more similar to the United States (Figure 9),

where VKT per licensed driver is having the largest negative influence on total VKT. This suggests that in both Canada and the U.S., the main factor responsible for recent changes in vehicle use is a behavioural shift, where people are driving less.

An examination of vehicle use and licensing rates among age groups may shed more light on individual driving behaviour. When vehicle kilometres driven per licensed driver is broken down by age group, it appears that young drivers under the age of 24 have had the largest negative contribution, both in Canada and the United States (Figure 10). Young adults in Canada drive substantially less each year than their American counterparts. In Canada, 25 to 44-year olds are also reducing their vehicle use, although this does not appear to be the case in the U.S (Figure 10). On the other hand, in both countries, seniors increased their car use during this period, which is particularly apparent among Canadian seniors (Figure 10).

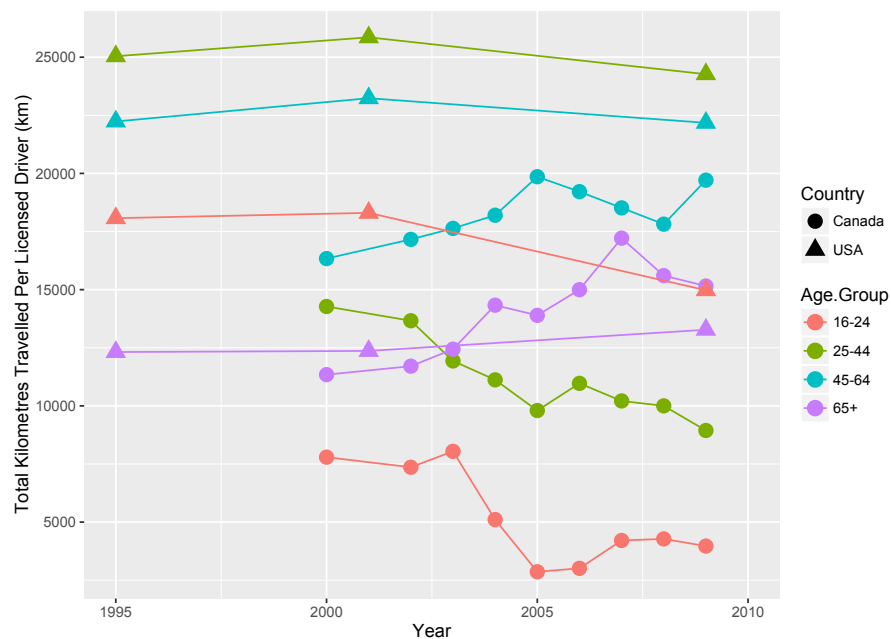


Figure 10. Total vehicle kilometres per licensed driver, by drivers' age group, in Canada (2000-2009) and the United States (1995-2009).

In terms of licensing rates, the share of licensed drivers under the age of 24 and over 65 is much lower than the rest of the population, both in the U.S. and Canada (Figure 11). Although licensing rates

did not have a significant effect on aggregate VKT, it is nonetheless quite clear that in the United States since 1995, the licensing rate for seniors was rapidly growing, while falling for young adults (Figure 11).

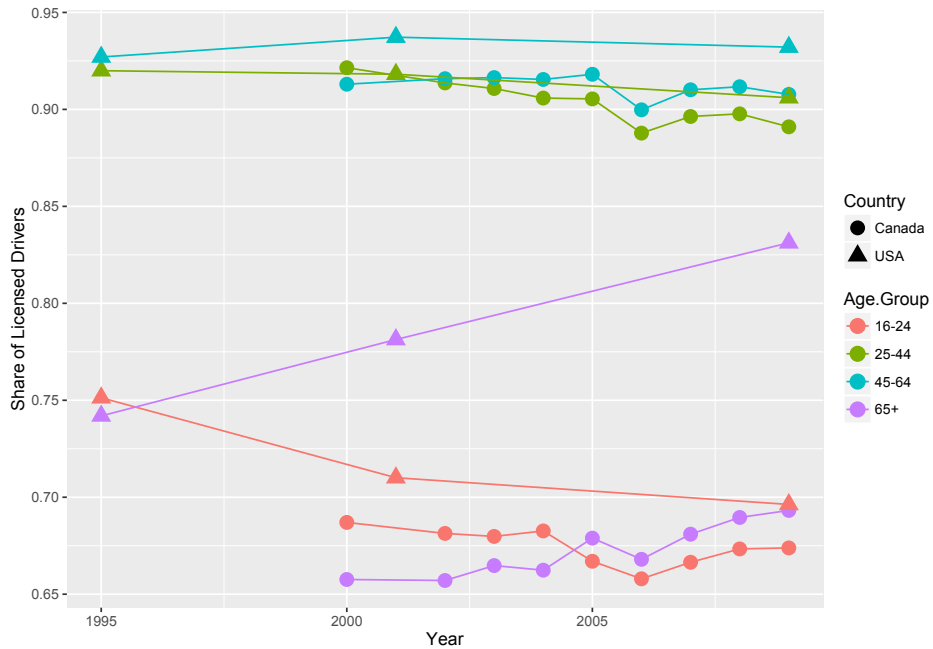


Figure 11. The share of licensed drivers, by drivers’ age group, in Canada (2000-2009) and the United States (1995-2009).

Effects of Gasoline Price, Income, and Urbanization

According to the decomposition analysis, the main factor responsible for plateauing or declining vehicle use is a change in behaviour, where people are driving less, particularly young adults. However, it is not clear what is responsible for this shift in behaviour. A regression analysis can tell us how gasoline prices, income, and urbanization are affecting driving behaviour. Table 1 displays regression analyses results for all four models, the pooled regression (column 1), province-fixed effects (column 2), time-fixed effects (column 3), and both time- and province- fixed effects (column 4). The province-fixed effects model controls for variables which vary between provinces but are constant over time, while the time-fixed effects model controls for variables which vary over time but are constant between provinces. The

model with both fixed effects (column 4) provides the most robust estimates. The adjusted R^2 values vary between 0.58 and 0.77, indicating that the models predict the data well.

Table 1. Multiple regression results for a pooled model, province-fixed effects model, time-fixed effects model, and both province- and time-fixed effects model, using per capita vehicle kilometres travelled as the dependent variable.

	log(per capita km travelled)			
	pooled	province fixed	time fixed	prov+time fixed
log(gasprice)	-0.302*** (0.072)	-0.119* (0.069)	-0.702*** (0.207)	-0.724*** (0.191)
log(medianincome)	0.860*** (0.094)	0.339*** (0.110)	0.871*** (0.120)	0.119 (0.161)
percent.urban	-0.012*** (0.001)	-0.0004 (0.007)	-0.012*** (0.001)	-0.003 (0.009)
percent1824	-0.088*** (0.015)	-0.051*** (0.014)	-0.084*** (0.017)	-0.039** (0.016)
percent65pl	0.010 (0.008)	0.012 (0.010)	0.017** (0.009)	0.014 (0.013)
Constant	1.565 (1.013)	5.839*** (1.184)	1.318 (1.279)	8.260*** (1.940)
Observations	240	240	240	240
Adjusted R^2	0.576	0.772	0.559	0.769
Residual Std. Error	0.119 (df = 234)	0.087 (df = 225)	0.121 (df = 211)	0.088 (df = 202)

Note:

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Estimates from the regression suggest that elasticities of per capita vehicle kilometres with respect to gasoline price vary between -0.12 to -0.72, with the latter estimated from the most robust model. This is somewhat higher than recent estimates of elasticities of driving demand with respect to gas prices found in the literature, which vary around -0.1 or -0.2 (Gillingham et al. 2015; Gillingham 2014; Barla et al. 2009). The divergence may be due to the simplicity of the model; specifically, variables which influence vehicle use may have been omitted. For instance, variables which change over time *and* within provinces are omitted, as are local policies and weather and snow events.

In order to determine how gas prices have influenced VKT in the last 25 years, a counterfactual scenario was estimated in which gas prices were fixed at their 1999 price (Table 2; Figure 12). The predicted scenario with observed variables (Table 2, row 2) is a very close fit to the observed, real pattern in VKT (Table 2, row 1), indicating that the predictions from the counterfactual scenario are robust.

Table 2. Estimates of per capita VKT in 2013, as well as percent divergence from the observed 2013 per capita VKT, using counterfactual scenarios from the fixed-effects regression model in which gas prices are fixed at the year 1999.

Counterfactual Scenario	Per Capita VKT in 2013	% Difference from Observed Scenario
Observed baseline condition	9014.86	--
Predicted scenario with observed variables	8738.73	-3.06
Fixed gas price	12825.40	42.27

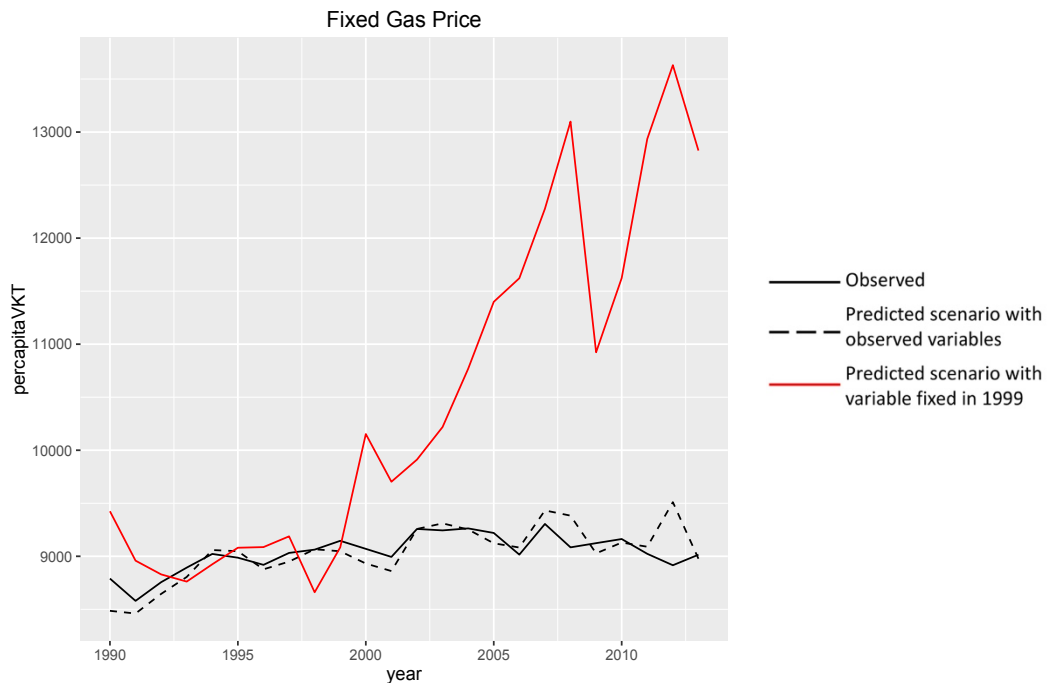


Figure 12. Per capita VKT from 1990 to 2013 under observed conditions, under a predicted scenario with observed changes in variables, and a scenario in which gas prices are fixed at their 1999 prices.

From 1990 to 2013, per capita VKT increased by 2.56%, reaching 9014 km travelled per person in 2013. During this time, inflation-controlled gas prices in Canada grew by approximately 38%, peaking in 2008. However, according to the counterfactual scenario, if gas prices had stayed at their 1999 levels, per capita VKT would have increased to 12825.4 km per person, 42% higher than the observed per capita VKT (Table 3; Figure 12). This suggests that the steady increase in gas prices in the first decade of the 21st century discouraged driving in Canada. If gas prices had not risen, but all other variables had increased as they did, per capita VKT would have likely increased substantially.

The income elasticity of vehicle use is estimated to be between 0.34 and 0.87 for the pooled, province-fixed, and time-fixed effects regression, but is insignificant in the model with both province- and time-fixed effects. Barla et al. (2009) estimated a GDP elasticity of driving demand of 0.2 to 0.3 in Canada, which is reflective of our province-fixed effects estimation. The model used in Barla et al. (2009) was much more complex, and could capture much more variation in GDP. Contrarily, our model was much more simple, and used median income, which has not varied much over the last 25 years. Most of the income variation in Canada is between provinces, rather than over time. For this reason, the model cannot easily assess the influence of median income with respect to per capita VKT, as variation in income is small. However, given that the relationship between income and per capita VKT is very significant for pooled, province-fixed, and time-fixed effects regressions, we can be quite certain that income is having some effect on per capita VKT. As well, as discussed in the previous section, the assumption of a linear relationship between the independent and dependent variables is not met perfectly with income, making results for income elasticity less trustworthy.

In order to determine how income has influenced VKT in the last 25 years, a second counterfactual scenario was estimated, with income fixed in 1999 (Table 3; Figure 13). Since the effect of income is insignificant for the regression with both time- and province-fixed effects, the counterfactual scenario for income VKT estimated using the time-fixed regression. As a result, the predicted scenario with observed variables (Table 3, row 2) is a not as close a fit to the observed, real pattern in VKT (Table 2, row 1), compared to the previous counterfactual scenario. However, the fit is still relatively accurate, and conclusions can still be drawn.

Table 3. Estimates of per capita VKT in 2013, as well as percent divergence from the observed 2013 per capita VKT, using counterfactual scenarios from the time-fixed regression model in which income is fixed to its 1999 level.

Counterfactual Scenario	Per Capita VKT in 2013	% Difference from Observed Scenario
Observed baseline condition	9014.86	--
Predicted scenario with observed variables	8181.93	-9.24
Fixed income	6793.76	-24.64



Figure 13. Per capita VKT from 1990 to 2013 under observed conditions, under a predicted scenario with observed changes in variables, and a scenario in which income is fixed at its 1999 level.

From 1990 to 2013, median income in Canada increased by roughly 19%. According to the counterfactual scenario, if income had stopped growing after 1999, per capita VKT would have been almost 25% lower than observed, decreasing to 6793 km per person (Figure 13). This suggests that income has a strong, positive influence on per capita VKT, pushing vehicle use upwards as it grows.

In terms of urbanization, when all other factors are held constant, the elasticity of per capita VKT with respect to increasing urban population appears to be -0.012 for pooled and time-fixed models (Table 1), indicating a small effect of urbanization. However, the relationship between per capita VKT and the share of urban dwellers is insignificant in province-fixed effect model and the model with both province- and time-fixed effects. For this reason, a counterfactual scenario was not estimated for the effect of growing urbanization in Canada. Like income, the insignificance of the relationship may be the result of low variability for the share of people residing in urban areas, or other reasons which are further reviewed in the discussion section below.

According to the fixed-effects regression models, per capita VKT elasticities with respect to the 18-24 age group varies between -0.039 to -0.088, while the over 65 age group is insignificantly related to per capita VKT. In a counter-factual scenario in which both age groups are fixed in 1990, per capita VKT was 5.41% lower than the observed pattern (Table 4; Figure 14).

Table 4. Estimates of per capita VKT in 2013, as well as percent divergence from the observed 2013 per capita VKT, using counterfactual scenarios from the fixed-effects regression model in age structure is fixed in 1990.

Counterfactual Scenario	Per Capita VKT by 2013	% Difference from Observed Scenario
Observed baseline condition	9014.86	--
Predicted scenario with observed variables	8738.73	-3.06
No change in age structure	8527.42	-5.41



Figure 14. Per capita VKT from 1990 to 2013 under observed conditions, under a predicted scenario with observed changes in variables, and for a scenario in which both age groups are fixed in 1990.

The regression results and counterfactual scenario for age groups suggest that demographic change has had a minimal impact on vehicle use in Canada, which is consistent with results from the IDA.

DISCUSSION

Comparisons Between Canada and the United States

Like many other OECD countries (Millard-Ball and Schipper 2011), American vehicle use has changed over the last 15 years, unprecedented in many decades. Canada is unusual compared to other countries, in that the change in driving trends is quite moderate. Furthermore, the yearly per capita VKT is substantially lower in Canada than in the United States. It is unclear why overall trends in Canada differ from other countries, yet according to the decomposition analysis, the factors responsible for elevating and dampening VKT are comparable between Canada and the U.S.

Individual driving preferences appear to favour less vehicle use after 2001 in the U.S. and in most years in Canada between 2000 and 2009. Driving patterns among age groups also appear to be very similar between the two countries, as discussed in the next section. Likewise, in both countries, population growth consistently pushed vehicle use upwards, while licensing rates had almost no effect. Given the strong influence of population, one might ask whether the difference between the U.S. and Canada could be attributed to differences in population size. Although the United States has a much higher population, the growth rate has been relatively comparable between the two countries. Likewise, the U.S. is much wealthier than Canada, and differences could be the result of different incomes. However, like population, the growth rates of income and GDP have been relatively comparable between Canada and the United States. Nonetheless, population and income are worthwhile concepts to examine in future research. Gas prices could also explain differences between vehicle use in Canada and the U.S., although gasoline prices are set by the international market, and should be comparable between countries, albeit with some variation due to local policies and taxes. The built environment, specifically urban and suburban sprawl, may also help to explain why Canadian per capita driving is much

lower than the U.S., although this has not been studied explicitly. Another possible explanation for the difference could be that Canada hit a plateau in vehicle use much earlier than other countries, before the 1990s, although without long-term data, this cannot be proven. As well, the more pronounced difference in driving habits between young adults and seniors, compared to American age groups, could be counteracting each other and producing a flatter trend overall.

Structural Factors Responsible for Changing Vehicle Use

Driving Trends Among Age Groups

Previously, seniors typically drove less, as they no longer commuted to work or shepherded around their children once retired (US EIA 2013; Dutzik and Baxandall 2013). However, today older Canadians and Americans are driving more than even before. One possible reason for the increase may be the result of lengthening life expectancies, where seniors are living more mobile, healthier, and longer lives (Statistics Canada 2012; Metz 2012). In addition, the current generation of seniors would have been born in the 1940s or earlier, and most would have actively participated in the “love affair with the car,” which dominated travel trends in North America for decades. Thus, the increase in driving among seniors could be explained by the most car-dependent adults reaching retirement, who are increasingly living longer, healthier lives.

Learning to drive was considered an important rite of passage for teenagers, and owning a car was critical to adulthood (Goodwin 2012A). Yet today, the largest negative contributors to vehicle use in Canada and the U.S. are young adults, who are demonstrably driving less each year. This pattern is also observed in many European countries (Kuhnimhof et al. 2012; 2013; Goodwin and Van Dender 2013). Young adults are entering the work force much later compared to previous generations, as more youth are now attending university and struggling to secure jobs and stable careers (Kuhnimhof et al. 2012).

As well, most young women are now pursuing their own careers (Gill et al. 2014), delaying marriage and the “settling down” of young couples (Statistics Canada 2014), which in the past often necessitated owning a car. For example, today the average marrying age is around 30, while in 1971 it was around 23 (Roberts 2005). Furthermore, Canada has experienced a widening income gap between young and older Canadians within the last 30 years (Gill et al. 2014). The regression results indicate that income has exhibited a positive influence on vehicle use, and thus the same must be true with declining income and declining car travel among young adults.

One could argue that since the proportion of young licensed drivers has not changed significantly over the last decade, perhaps young adults intend to eventually follow in the footsteps of their parents’ heavy car use, despite economic uncertainties. On the other hand, if attitudes towards the car are in fact changing, one could say that the relatively stable license rate could be residual effects of a strong car culture which lasted for the better half of the century. Either way, habits and practises that are developed in early adulthood are often kept for a lifetime. For instance, a strong predictor of an individual’s likelihood to vote is whether they voted in elections during early adulthood (Coppock and Green 2015). If this is also true for driving behaviour, we may see less driving by middle-aged adults in the next few decades, as the current generation of young adults grows older.

An Aging Population

Previously, we hypothesized that the aging Canadian population could be playing a role in declining vehicle use, since older drivers, who are growing in numbers, were thought to drive less compared to younger people. According to both decomposition and regression analyses, demographic shifts are playing a very small role. Kuhnimhof et al. (2013) also found that aging populations played a small role in driving patterns of four western countries. In Canada, the share of seniors, who are driving

more, is increasing in Canada, while the share of young adults, who are driving less, is shrinking. These two coupled trends, of both shifting demographics and vehicle use within age groups, could be together reducing vehicle use in Canada and abroad, rather than simply changes in demographics on its own.

Urbanization

Growing urban populations and the densification of cities could also be playing a role in Canadian vehicle use, as it has in other countries (Headicar 2013; Newman and Kenworthy 2011; Metz 2013; Goodwin and Van Dender 2013). Canada is becoming increasingly urbanized; 81% of Canadians now live in cities, with Ontario, British Columbia, Alberta hosting the largest urban populations (Employment and Social Development Canada 2016B). Interestingly, the latter two provinces have the most pronounced decline in vehicle use. Unfortunately, data did not exist to decompose driving demand in terms of urbanization. However, results from the regression analysis suggest growing urbanization is having no effect on per capita vehicle use. This differs from the expected negative contribution of urbanization, which is discussed extensively in the literature (Headicar 2013; Newman and Kenworthy 2011; Metz 2013; Goodwin and Van Dender 2013). However, Canadian cities are very different from European ones, where the bulk of peak car research has been conducted (Kuhnimhof et al. 2012; 2013; Metz 2013; Headicar 2013). Although cities such as Toronto, Vancouver, and Montreal have large public transit systems, other urban centres still have relatively limited options. Even if gas prices are high, or people desire to drive less, vehicle use will still be relatively inelastic in areas without reliable alternative forms of transportation. Furthermore, many Canadian cities are locked into a legacy of urban sprawl, especially newer cities or those which experienced massive post-war booms. Sprawling cities require vehicle travel for even short trips (Kenworthy and Laube 1996). Consequently, those that register as urban dwellers in the Canadian Census may in fact be locked into areas still requiring heavy vehicle use where there are

few alternative transportation options. Moreover, dense cities like Toronto and Montreal have always had relatively low vehicle use to begin with (Kenworthy and Laube 1996), and thus may have not reduced car demand noticeably over the last two decades. This is especially notable given that one third of Canadians live in Toronto, Montreal, and Vancouver (Employment and Social Development Canada 2016B). Finally, the share of people living in urban centres has changed very little over the period of 1990 to 2013, making it difficult for the regression to measure any influence of urbanization. The inability to include urbanization in the index decomposition analysis creates a major limitation, and should be considered for future research, as well as for data collection with respect to vehicle use. Furthermore, definitions of urban dwelling types should be expanded to separate suburban from urban settlement areas.

A factor that is clearly responsible for *declining* vehicle use in Canada is a behavioural change, whereby drivers are actively driving less. This may be due to economic factors, gas prices, or otherwise. These ideas will be further explored in the next section.

Behavioural Factors Responsible for Changing Vehicle Use

Although Canada has not exhibited a dramatic change in vehicle use overall compared to other countries, provinces differ substantially. Some provinces have experienced a significant decline in per capita car travel since the 1990s, such as British Columbia and Alberta, while other provinces experienced a rapid increase, such as Saskatchewan. Unfortunately, due to data limitations, it was not possible to do a decomposition analysis for each province. Nonetheless, these provincial variations could be due to local economic conditions, urban and rural spatial patterns, and local policies and taxes. Results from the regression analysis may provide some clues as to why some provinces in Canada are so markedly different with respect to vehicle use.

The Effect of Gas Prices

Based on the counterfactual scenarios, Canadian per capita VKT would have been 42% higher had gas prices not risen roughly 59% from 1999 to 2013. This suggests that gas prices were at least partly responsible for the declining growth in Canadian vehicle use after the turn of the millennia. However, as mentioned previously, changes in vehicle use in Canada are not very clear without longer term data. For instance, it would have been useful to know how gas prices influenced VKT over the period of growth before the turn of the 21st century, yet this data is not available. Nonetheless, gas prices may explain some differences between provinces, as prices vary significantly between jurisdictions in Canada.

British Columbia experienced a 51.23% increase in gas prices from 1990 to 2013, the largest increase in Canada over the period of study. In 2008, British Columbia implemented a carbon tax, now priced at \$30 per tonne of carbon dioxide equivalent per year, which has resulted in higher prices at the gas pump. During this period, no other provinces had significant carbon pricing mechanisms in place. From 2008 to 2011, greenhouse gas emissions in B.C. fell by 10% compared to the rest of the country (Elgie and McClay 2013), and by 2013, use of fuels subject to the tax, including gasoline, declined by over 16% within the province, and 19% relative to the rest of Canada (Pedersen and Elgie 2015). In fact, Rivers and Schaufele (2013) found that in the first four years of B.C.'s carbon tax, carbon dioxide emissions from gasoline consumption were reduced by 3.6 million tonnes. According to our results, B.C. also experienced one of the largest declines in per capita car use, dropping 15.7% between 1990 and 2013. According to the counterfactual scenario, if gas prices had not increased after the year 1999, per capita VKT in B.C. would have risen dramatically (Figure 15). Of course, the effect of gas prices on driving trends in B.C. cannot be proved with certainty, but the results suggest at least some effect.



Figure 15. Per capita VKT in British Columbia from 1990 to 2013 under observed conditions, under a predicted scenario with observed changes in variables, and for a scenario in which gas prices are fixed in 1999.

The case of Alberta demonstrates that the shift in car use cannot be the result of higher gas prices alone. Alberta saw a 23% decline in per capita driving from 1990 to 2013, the largest in Canada. However, over this period, Alberta had the smallest percent change in gas prices, increasing by only 20.5%. Although gas prices may not always be a key factor in driving trends, future carbon pricing set to be implemented in Alberta and Ontario will provide further opportunities to assess the effects of carbon taxes on vehicle use.

The Effect of Income

Previous research in the U.S. and U.K. suggest that the “peak car” decline is unlikely related to income, as vehicle use and GDP began to decouple in the last decade (Millard-Ball and Schipper 2011; U.S. EIA 2014; Metz 2012; Metz 2013; Le Vine et al. 2009). As well, the downturn in American vehicle use occurred before the 2008 recession (Figure 1). In terms of income, our results are relatively inconclusive,

although three of the four regressions suggest that increasing income is exerting a positive influence on per capita VKT, pushing vehicle use upwards somewhat. However, as the relationship between income and per capita VKT is not linear, regression results may be biased.

Given that income is likely linked to changes in VKT, financial pressures for young adults could be playing a role in the observed decline in driving for that age group, as discussed previously. Although it was not quantified in this study, the effect of declining income for young adults is an important future area of research. This is particularly notable as Canada has some of the worst intergenerational income disparity compared to other similar countries (Gill et al. 2014).

The effect of income could also account for some differences between provinces. Saskatchewan saw enormous growth in prosperity over the last two decades, with the median income increasing by 46.18% from 1990 to 2013. The per capita increase in VKT in Saskatchewan exceeded other provinces by a large magnitude, increasing almost 70% in 23 years. As well, provinces with the highest growth in per capita VKT, such as Newfoundland & Labrador (55.06%), Manitoba (27.42%), and Prince Edward Island (10.83%), all had strong growth in income (26.26%, 20.56%, and 20.09%, respectively).

It is important to note that the time frame for the decomposition analyses ended immediately after the 2008 global recession, which would have certainly affected vehicle use, particularly in the United States whose economy was hardest hit. Unfortunately, neither country's travel surveys go beyond 2009, so vehicle use was unable to be analyzed fully as the economy recovered. This is particularly notable given that GDP has historically played a large role in overall trends in vehicle use (Le Vine et al. 2009). In fact, there has been a slight increase in per capita VKT in the U.S. in the last two years, potentially suggesting a rebound in VKT. Of course, growth in VKT, whether or not short-lived,

could be due to numerous other factors as well, such as gas prices. Nonetheless, these are important trends to continue monitoring.

Other Explanatory Variables

Finally, changes in vehicle use could be the result of factors that are much more challenging to model. This could include shifts in youth culture and preference, as well as local policies. In recent decades, many jurisdictions, particularly cities, have implemented policies to encourage multi-modal behaviour. For instance, some roadways are now being shared, with designated lanes for buses or bicycles, rather than being reserved solely for car travel. Many cities are implementing policies designed to prevent single-person vehicle trips, such as car pooling stations and public transit park-and-go facilities. Future research should assess how overall vehicle trends are being affected by the convergence of multiple policies, infrastructure developments, and land-use planning strategies.

Caveats and Data Limitations

To date, there has been very little research conducted on Canadian vehicle use, especially using quantitative methods. However, it is important that we understand how vehicle use may or may not be changing in Canada, and what this means for the associated externalities, including traffic accidents, urban congestion, air pollution, and greenhouse gas emissions.

Unfortunately, the unreliability and poor quality of Canadian data has made it very challenging to identify long term trends and draw clear conclusions. Although data for national or provincial total VKT does exist, data was sparse for age related driving, and non-existent for urban and rural driving. Much of the issue surrounds travel surveys, the data of which is fragmented and poor. For instance, within the last 25 years there have been three surveys on household vehicle use in Canada, one from 1994 to 1996, one currently ongoing since 2013, and the one used in this study, from 2000 to 2009.

Although they ask similar questions and have similar objectives, the data has been presented in such a way that comparisons between surveys is not possible. Due to this incompatibility, the analysis in Canada was restricted to period from 2000 to 2009. This time frame is too short to draw clear conclusions, especially since it included a large atypical event, the 2008 global recession. This is also the case for non-survey data, including total VKT which is only available from 1990, making it impossible to capture long-term trends. When examining trends in the U.S., one can see how important it is to also include previous phases of growth, before the period of interest.

Some data, such as driver licenses, is only provided by provincial ministries, rather than from a central federal database. As a result, data on licensing rates was difficult to track down, and not all provinces could provide data for every year, or data at all. Subsequently, we were forced to impute the number of licenses at the national level, reducing the strength of our analyses. Data on car ownership is also provided by provinces, but due to the difficulty in tracking down the data, car ownership could not be included in the analysis.

Another issue was that the data did not allow for provincial comparisons of vehicle use in terms of age groups. As mentioned above, trends differ substantially between provinces, and assessing these trends on a province-by-province basis would have been extremely beneficial.

The deficiency of Canadian data is particularly evident when comparing vehicle use to the United States. The American travel surveys date further back, and the two American survey types are designed to be comparable. Furthermore, trends among age groups, location and settlement types, as well as for different modes of transportation and other important variables, are easily measurable. In comparison, it is very difficult to make conclusions about Canada with such poor quality data and without being able to capture long-term trends in vehicle use.

Finally, one must take caution in the comparison of trends between two countries. Specifically, Canada and the United States have different data sources and collection methods. For one, the travel surveys are very different; the American version is much more sophisticated, uses a much larger sample size, and could possibly use different statistical methods. As well, other forms of data could be different, in terms of collection methods or statistical approaches, such as vehicle kilometres travelled. As a result, comparisons in vehicle use between countries should be taken with a grain of salt. It should also be noted that this research is purely speculative; the above analyses include no experimentation and thus cause and effect cannot be ascertained. Nonetheless, as discussed, we can be reasonably confident with the conclusions, based on multiple sets of analyses.

CONCLUSION & IMPLICATIONS

It is unclear why Canadian vehicle use differs from other countries, showing less growth and a more muted plateau in per capita driving. However, contributing factors to vehicle use seem to be similar between Canada and the United States, with young adults driving less and seniors driving more each year.

It has been established that young adults are driving less; the question remains whether this is due to economic factors or other social or cultural shifts. If economic factors are playing a larger role, then we may see a surge in VKT as Canadian Millennials reach their 30s, enter the workforce, and earn more. However, if the habits of young adults are set in stone now, the change may become more cultural, and thus we may not see millennial vehicle use rebound, potentially impacting Canadian vehicle use as a whole dramatically.

Today, population growth and income are both having a notable positive influence on driving trends in Canada. In light of the expectation that both of these factors will continue increasing in the coming decades, decision-makers ought to consider policies that will limit vehicle use. An interesting factor to consider is the arrival of new immigrants, now accounting for two thirds of population growth in Canada (Statistics Canada 2015), who may have different cultural relationships with the car. For instance, if the “American, or Canadian, Dream” of owning a house with multiple cars in the suburbs is not longer true for many established Canadians, this may still be very important to new immigrants.

Gasoline is an internationally traded commodity, and gas prices are set by the global market. For this reason, it is impossible to know how gas prices will change in the coming decades. However, based on the results from national trends, as well as in British Columbia, recent increases in gas prices have likely prevented growth in per capita VKT. Given the large externalities associated with driving, such as

greenhouse gas emissions, traffic accidents, urban congestion, and air pollution, jurisdictions in Canada and abroad may want to consider carbon or gasoline taxes to limit growth in vehicle use. Contrarily, if gas prices fall in the coming decades, vehicle use could grow, as will the associated external costs.

Transportation planners cannot know the future, and trends require ongoing examination. Overall, income and population growth are responsible for pushing vehicle use upwards, while behavioural shifts, in part due to gas prices, are responsible for pushing vehicle use downwards. Other cultural or social aspects may also be at play. Most importantly, Canadians and Americans have been driving less on average in the last decade or so, with young adults leading the trend. Regardless of the future trajectory of vehicle use, policies to curb the external costs of driving must be considered.

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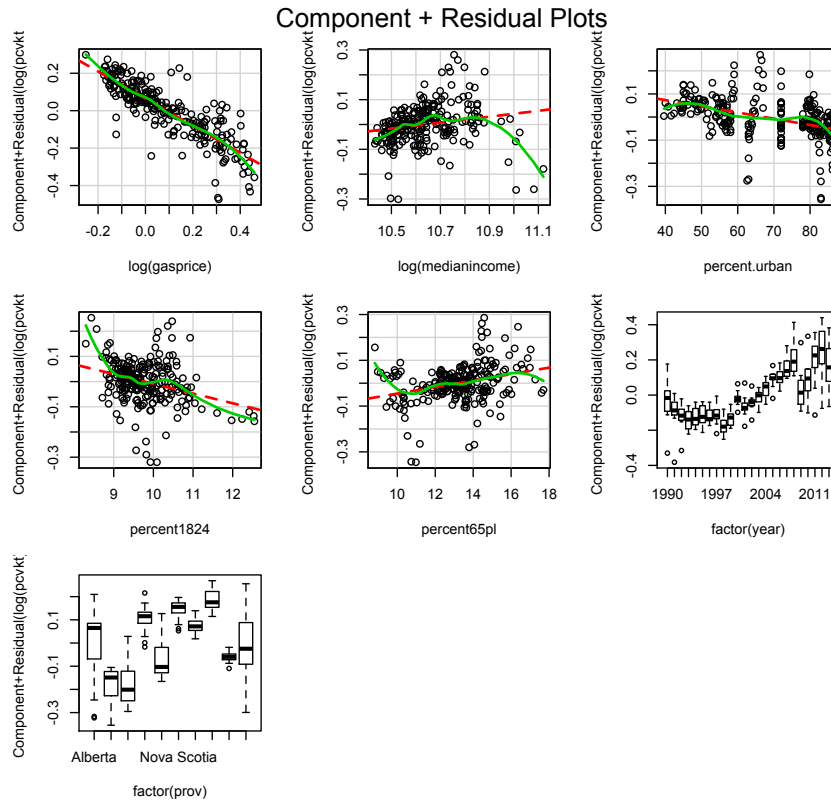
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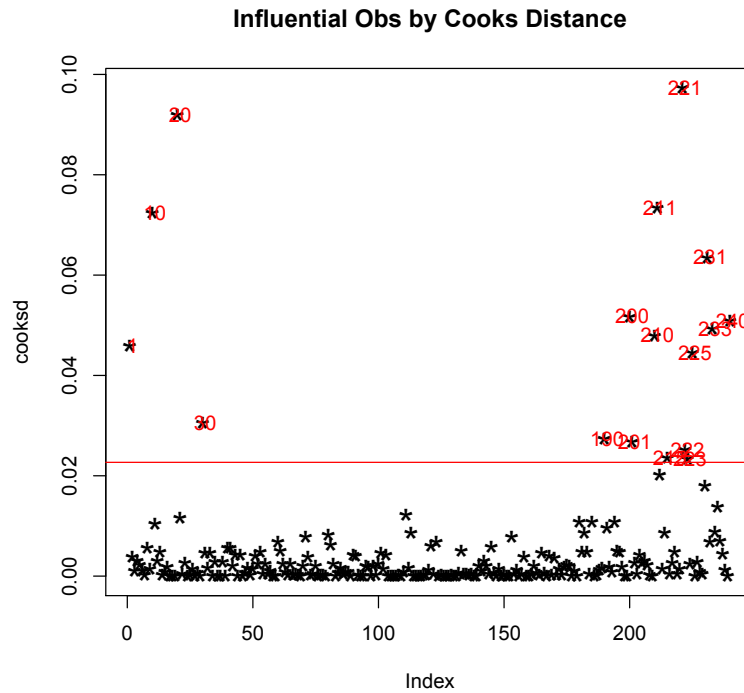
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APPENDICES

Appendix 1: Non-linearity of median income



Appendix 2: Outliers



Appendix 3. Other assumptions of the linear regression model.

