Who Will Take the Toll?

An equity evaluation of the proposal by the City of Toronto to toll the Gardiner Expressway and the Don Valley Parkway

Supervised Research Project
Submitted in partial fulfillment of the Master of Urban Planning Degree at McGill University

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Who will take the toll? An equity evaluation of the proposal by the City of Toronto to toll the Gardiner Expressway and the Don Valley Parkway

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ISSUE: Road pricing has gained recent attention in North America following successful programs that have reduced congestion and funded public transit in cities such as London and Stockholm. However, every urban region is unique, and spatial differences in income distribution and public transit accessibility play a crucial role in determining if a given road pricing scheme will be a success.

This study evaluates the impacts of the proposed Gardiner Expressway and Don Valley Parkway tolls on workers from different income groups and neighbourhoods in the Greater Toronto and Hamilton Area (GTHA).

CONTEXT: In 2016, Toronto City council voted in favour of a policy to toll the Gardiner Expressway (Gardiner) and Don Valley Parkway (DVP). Their motivation was two-fold: 1) to help fund the $3.6 billion replacement and maintenance of large sections of the aging Gardiner, and 2) to fund $33 billion in public transit improvements in Toronto by 2045. The Province of Ontario rejected the policy, citing insufficient research on the financial impacts on GTHA residents as the main reason for not allowing Toronto to exercise its tolling powers.

APPROACH: 2016 census data commuter flows and ArcGIS network analysis were used to predict which workers in the GTHA use the Gardiner/DVP to reach their work locations. The income breakdown of these workers was compiled at the regional, municipal and census tract (CT) levels to establish if any geographical areas of the GTHA, or populations in specific income brackets, will be disproportionately impacted by the proposed policy.

RESULTS: Based on current travel patterns, the policy will impact about 184,000 workers living in the GTHA, 63% of whom reside in Toronto. The income breakdown of impacted workers is similar in all municipalities in the region.

There is a smaller share of low-income (individuals earning less than $40K) workers among the impacted population compared to the working population as a whole. This is because many already choose to use other modes to get to work. That said, there are 56,000 impacted low-income workers, many of whom are likely to be captive to driving and will have to find alternative routes or re-locate in order to avoid paying the tolls, which will impact their overall quality of life.

Proportionately, higher-income workers are more likely to pay the toll since they tend to drive to work more. However, relative to lower-income workers, the same toll will have less of a financial burden on these groups.

After-tax personal income breakdown in the GTHA

RECOMMENDATIONS

- **Explore options for public transit improvements and other forms of toll revenue distribution that will benefit impacted low-income communities directly.**
- **Invest in road pricing infrastructure that will allow for variable tolling options such as distance- and time-based pricing.**
- **Consider repurposing existing highway lanes as High Occupancy Toll (HOT) lanes.**
- **Conduct a pilot project and evaluate the actual impacts of the chosen pricing strategy on the population and flow of traffic.**

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1. INTRODUCTION

In the Greater Toronto and Hamilton Area (GTHA), traffic congestion has become increasingly problematic, and many of the city's roads and highways are in need of significant repair (City of Toronto, 2016). Time lost by commuters in traffic congestion is estimated to cost at least $6 billion in lost productivity with this value set to increase to $15 billion by 2031 if congestion keeps progressing at the same rate (Toronto Region Board of Trade, 2013). These figures do not include the social and environmental costs of stress, time wasted, and pollution that are often overlooked by policy-makers (Kockelman & Lemp, 2011). Highway congestion is made worse because public transit systems in the GTHA best serve areas closer to the city centre, while increasingly much of the working population lives and/or works in parts of the region that are in need of substantial public transit improvements (Hulchanski, 2010; Metrolinx, 2008). As a result, low- to middle-income residents — individuals making $60K after-tax per year or less — outside of the city centre often have limited public transit access. These individuals and those in their households tend to be more prone, or captive, to personal automobile use (El-Geneidy, Buliung, et al., 2016).

Issues of traffic congestion and infrastructure funding are certainly not limited to the GTHA; they are a topic of concern worldwide in large cities in Asia, Europe, and across North America (Kockelman & Lemp, 2011). In highly congested areas, uncapped and "free" usage of infrastructure significantly slows down all road users, leads to a loss in productivity, has a greater environmental impact, and puts increased stress on aging transportation infrastructure (Kockelman & Kalmanje, 2005). Many of the world's largest metropolitan areas have implemented road pricing in the form of flat highway tolls (usually used to fund highway maintenance directly), or congestion pricing (CP), which varies depending on time of day and level of crowding on roadways (Ecola & Light, 2009). These strategies have been implemented in an attempt to both subsidize transportation network maintenance and expansion, and to limit the economic, social and environmental costs of roadway congestion (Levinson, 2010; Otaki, Imanishi, Miyatake, Nemoto, & Uchiyama, 2017). If the funds raised by road pricing can increase the budget that cities have to spend on infrastructure, it will also make it possible to complete large repairs that in the long run will extend the life of the roads and limit delays due to closures for repairs (Venter & Joubert, 2014).

This study seeks to build on the research proposed by the City of Toronto to understand who will be impacted by highway tolling on the Gardiner Expressway (Gardiner) and the Don Valley Parkway (DVP). It has been estimated that up to 40% of highway users were from outside of the City of Toronto, beyond the neighbourhoods directly adjacent to the highways (Lupton & Janus, 2016). From a political perspective it is crucial to also understand the characteristics of these users to predict equity impacts (Ecola & Light, 2009; Levinson, 2010; Small, 1992). The toll proposed by the City of Toronto that will be applicable to all road users is the first of its kind in Canada. It may very well open up the debate in other municipalities dealing with similar issues of congestion and infrastructure deficits. For example, in Metro Vancouver the discussion over the fairness of congestion pricing began to heat up in early 2018 (Lee, 2018; Little, 2018). If road pricing is to be seen as an acceptable policy in Canadian cities, the main obstacle will be the debate over which communities will be most impacted, and how to ensure that all commuters are paying their fair share. This diagnostic study is an evaluation of the impacts on different income groups in the GTHA, and it is an important component in the development of an equitable tolling strategy for the Gardiner and DVP highway corridors, and potentially for the region as a whole.

This study uses a street network analysis in ArcGIS and place of home and work data from the 2016 census conducted by Statistics Canada (Statistics Canada, 2016), to answer the following central research questions:

- Based on existing data on individual trips and the road network, what is the income profile of the GTHA workers who are likely to use the DVP and Gardiner for regular trips to work?
- What is the share of low and low-middle income individuals among likely DVP/Gardiner users?
- Are these individuals concentrated in specific neighbourhoods or areas in the GTHA?

This study begins with a review of global road pricing strategies and the related equity impacts and how these may apply to the GTHA region. The methodology used to estimate the number of workers using the roadways goes beyond the nearby neighbourhoods to better understand the income characteristics of all users of the Gardiner and DVP. Although it is beyond the scope of this project, the methodology developed here could also be used to model the effect these tolls and others in the GTHA will have on congested travel-times and gain an understanding of important time-saving benefits of such a policy. The study concludes with a discussion and recommendations for the City of Toronto of the most equitable practices in road pricing. These include not only options listed in the City's proposal, but other strategies which may be more politically and economically feasible in the given context.

1.1 Study Context

The Greater Toronto and Hamilton (GTHA) region is an agglomeration of municipalities found at the west end of Lake Ontario that encompass the City of Toronto. The GTHA has a population of 7.1 million people and a land area of 8500 km^2 (figure 1). Traditionally, users of the City of Toronto's highways have not been subjected to tolls; transit infrastructure projects were funded in large part by the gas tax levied on consumers. However, in 2016 Toronto City Council voted in favour of implementing a flat toll on two heavily-used highways owned by the City: the Gardiner and the DVP.

Figure 1. The GTHA study area and Gardiner Expressway and Don Valley Parkway

The primary motivation for charging the toll was to fund repairs on the Gardiner, especially in the downtown core where many of the overpasses and bridges are in need of repairs or replacement (figure 2). The cost of these repairs has been ever-increasing, with recent estimates going as high as $3.6 billion (Rieti, 2016). Because the highways are city-owned, the City is responsible for funding this repair and without investments from the provincial and federal governments, they needed to find a way to fill the infrastructure gap. Mayor John Tory and the Toronto City Council also saw this as an opportunity to address increasing congestion issues on Toronto's highways by raising funds for public transit investments that would provide GTHA residents with improved alternatives to driving (Lupton & Janus, 2016).

Figure 2. The aging Gardiner Expressway on Toronto's waterfront (Llewellyn, 2016)

The initial proposal was to charge a flat $2-$3 toll for each user of the highway, regardless of distance traveled. This road pricing scheme was developed in response to a chronic lack of funding for transit in the City of Toronto as successive municipal governments have been unwilling to implement sustainable sources for infrastructure spending (Powell, 2016). It proposed additional research on the potential impacts of the tolls in the neighbourhoods adjacent to the highways (City of Toronto, 2015). Despite the highways being under the jurisdiction of the City, this policy required approval from the Province of Ontario who decided to reject it in January 2017. This decision was polarizing, as it meant the City of Toronto lost an estimated $200 million of potential revenue that was set to be invested in the repairs and public transit (Lupton & Janus, 2016). The province of Ontario later pledged to replace this lost revenue by doubling the share of the gas tax normally afforded to municipalities in the GTHA, increasing it to $170 million per year for the City of Toronto by 2021-22 (Crawley & Janus, 2017).

Despite this development, the road pricing debate is not over in the GTHA. The current budget does not allow for sufficient funds to address the root of the issue, which is a lack of alternative transport options for the vast majority of GTHA residents (Shum, 2017). The City has estimated that $33 billion would be required over the next 20 years in Toronto alone, which will require investment from a wide variety of sources (Lupton & Janus, 2016). The debate is expected to continue in the coming years as is evidenced by other discussions around road pricing in the region. For example, the Province of Ontario recently launched a two- to four- year high-occupancy toll (HOT) pilot on the Queen Elizabeth Way Highway (QEW), following a successful pilot during the Pan-Am games. Municipal leaders in Toronto's neighbouring communities, such as York Region, are also indicating their interest in having tolling powers to raise local revenue for transportation (The Regional Municipality of York Region, 2016). As these proposals to toll roads in the GTHA continue, the equity impacts of the strategies will continue to be an important obstacle for both the cities and the Province of Ontario to address.

2. LITERATURE REVIEW

2.1 Equity impacts of road pricing

The concepts of *vertical and horizontal equity* are important to discuss when considering adding a toll to a roadway that was previously un-tolled. Foth et al. (2013) describe vertical equity in transportation as the concept whereby “benefits are provided for one income group, often of low income, who cannot reasonably afford the price of transportation”. In economics, a commonly understood form of vertical equity is the idea that lower income groups pay less income tax, as a percentage, than higher income groups. A road pricing policy where drivers with an income below a certain threshold would be exempt from paying the toll, or would pay the toll at a reduced rate, would also been seen as vertically equitable (Ecola & Light, 2009; Farber, Bartholomew, Li, Páez, & Nurul Habib, 2014). However, operationalizing such an approach can be an issue, and there are very few examples of where such a policy has been implemented in practice. *Horizontal equity* is defined as a policy that provides similar opportunities, or similar impacts, to groups that are seen as being in the same socio-economic group (Ecola & Light, 2009). A common example of horizontal equity is the health care systems in most developed countries, with the USA as a notable exception, whereby all of the population with the same need has equal access to the same health care (Lu et al., 2007). An example of a tolling scheme that could be seen as horizontally *inequitable* is one where only certain highways are tolled in order to subsidize the construction of the entire network, or other infrastructure that benefits a different group of people from those paying the toll (Levinson, 2010).

In the simplest sense, measures of vertical and horizontal equity will use the income bracket of particular groups as the key metric to determine who pays more and for what. However, in the case of road pricing, other important factors such as travel-time lost due to congestion should also be considered when designing an appropriate policy for highway tolls (Kockelman & Kalmanje, 2005; Levinson, 2010; Ortega Alejandro, Vassallo José Manuel, & Pérez-Díaz Juan I., 2018). This is because all drivers on a particular section of highway are actually inhibiting other drivers from traveling faster (Kockelman & Lemp, 2011). For this reason a variety of equity studies are required to look not only at the income range of impacted groups, but also at the marginal social cost (MSC) that every commuter is inflicting on others by adding to highway congestion (Ecola & Light, 2009; Kockelman & Lemp, 2011). Ecola and Light (2009) describe a hypothetical scenario in which a roadway is priced such that it is too expensive for people below a certain income level to pay. In this example, only the higher income groups will use the road and must pay the toll, so the policy could be seen as vertically equitable from a purely income-based standpoint. However, because lower income groups are excluded from this road, they will undoubtedly add time to their commute, or be unable to access locations that they were previously able to access. Therefore, when the MSC of the toll is considered, it is in fact vertically inequitable.

Road pricing is a complex issue, and the optimal price for a given toll road is highly dependant on the objective of the tolling policy. In an ideal MSC congestion pricing model, all roads would be tolled according to the impact users are having on others (Ecola & Light, 2009). However, realistically it is most often the case that while one road is tolled, adjacent options remain available free of charge, resulting in a "second-best" tolling strategy (Kockelman & Lemp, 2011). Ortega et al. (2018) expand on this concept by acknowledging that when a toll is implemented on one road in a region, the access to viable alternative routes must also be considered. Therefore, policy-makers must work within the limitations of regions that have little or no previous road pricing history in order to develop strategies that will be effective and politically feasible.

2.2 Road pricing strategies

Just as there is a wide variety of potential factors contributing to the decision to toll a given highway, there is also a vast array of options available to policy-makers when deciding on pricing strategies and tolling methods. Each of these options may have unique pricing mechanisms and differing impacts on equity. The City of Toronto voted in favour of a flat toll for using the DVP or Gardiner, instead of a distance-based tolling scheme (City of Toronto, 2015). While the report considers a 50% reduction in toll-rates at night (8:00pm to 6:00am), tolls are not planned to vary with congestion levels, meaning it cannot be considered "congestion pricing" (Ecola & Light, 2009). However, this is not to say that eventually congestion pricing will not be a useful option in the GTHA. This section will give a brief overview of tolling and congestion pricing commonly used in North American and international jurisdictions. Following this, consideration will be given to the re-distribution of tolling revenue.

2.2.1 Models of roadway pricing

In their review of equity and congestion pricing, Ecola and Light (2009) identify five main categories of road pricing:

1) *Time-, distance-, and/or place-based pricing*: The price to use a road is adjusted based on distance traveled, location, time of day and vehicle type. Many countries in Europe such as Belgium, Germany and the Netherlands have implemented distance-based tolling schemes on heavy-duty trucks on their national roadways (Ecola & Light, 2009; HST Groep, 2018). These systems usually require the administration of an onboard unit in all vehicles.
2) *Cordon pricing*: A toll is charged each time a vehicle crosses a boundary. The amount charged generally varies by time (e.g., weekdays, weekends, peak/off-peak hours), and vehicles are not charged if they stay inside the boundary. This method has been applied in London and Stockholm (discussed later).
3) *Area-license systems:* Similar to cordon pricing, a vehicle is charged a toll if it crosses a boundary. However, the toll is a daily flat-fee and is only charged once even if the boundary is crossed multiple times. This method may seem fairer than cordon pricing, but it is also less effective at reducing congestion because drivers with permits have no incentive to reduce their trips. It was applied in Singapore from 1975 to 1988.
4) *High Occupancy Toll (HOT) Lanes:* A version of High Occupancy Vehicle (HOV) lanes that can be used for free by carpool vehicles and at a certain cost for other vehicles. The cost typically varies depending on time of day in order to control congestion. In recent years, HOT lanes have seen significant popularity on US highways such as in Houston where the "QuickRide" HOT-lane program began in 1998 (Burris & Stockton, 2004) and

in Minneapolis where HOT lanes have been active since 2005 (Minnesota Department of Transportation, 2016).

5) *Toll roads, bridges, and tunnels:* Tolls that are applied independently to individual routes, usually to repay bonds issued to finance their construction. In some cases, including on the Highway 407 express toll route (ETR) in Toronto, these tolls may vary depending on time of day. In many US states such as New York and New Jersey, toll roads with flat charges have been used in this manner, usually with an open or flat tolling system (McMahon, 2018).

Ecola and Light (2009) note that cordon pricing tends to be more commonly found in the European context, while HOT lanes have gained more traction in North America. This difference in approaches can be attributed to "local government structure, existing land-use patterns and the prevalence and use of public transportation".

2.2.2 Highway toll revenue re-distribution

The decision of what to do with potential tolling revenues is largely dependent on a region's budgetary situation and the goals they wish to achieve (Ecola & Light, 2009; Kockelman & Lemp, 2011; Levinson, 2010). The motivation for tolling roads includes, but is not limited to:

- Optimizing existing roadway use;
- Funding expressway maintenance and/or expansion;
- Funding public transit infrastructure improvements;
- Reducing congestion in order to reduce travel-times; and
- Encouraging a mode shift away from single-occupant vehicles to forms of transportation that reduce greenhouse gas emissions and air pollution.

In the case of the Gardiner and DVP, the primary motivation for tolling the highways is to fund expressway improvements along the proposed tolled routes (City of Toronto, 2015), and also to fund public transit improvements along the corridor (City of Toronto, 2016). This approach is similar to flat-toll schemes used to pay down bonds on many American roads, although an important difference is that the City of Toronto is also hoping to reduce congestion and raise surplus funds for public transit in the city. This type of funding strategy has similarities to the cordon pricing systems in Stockholm and London where additional revenues were successfully invested in public transit improvements that could accommodate increased usage (Eliasson, Hultkrantz, Nerhagen, & Rosqvist, 2009; Evans, 2007). What follows is an overview of the potential equity impacts of revenue redistribution schemes.

Roadway maintenance and highway expansion investment

In the North American context, the main goal of highway tolling is often to fund either the maintenance of current infrastructure, expansion of the roads, or building new highways. This form of funding is popular because improvements can be appreciated by the majority of the population, and because it is easy for users to see the link between the tolls and investments (Small, 1992). As with public transit, highway investment is often considered to be an equitable use of toll revenue if the investments are made on the same routes that impact those paying the tolls. However, it is not equitable if highway tolls on a popular route are used to fund the construction of unrelated projects (Ecola & Light, 2009; Levinson, 2010). In recent years, investment into HOT lanes has been found in many studies to be an equitable solution that also ranks highly in public opinion (Ecola & Light, 2009). Despite the fact that higher income groups use HOT lanes more, they also serve to alleviate congestion in the non-tolled lanes used by lower income travelers. Also, all travelers have the option to carpool, or to spend the amount required to use the HOT lanes on occasion when they need to (Patterson & Levinson, 2008).

Public transit investments

With the exception of investments directly into highway maintenance, the most politically feasible form of revenue redistribution in North America is likely to be the funding of public transit projects in the region. The equity of public transit investment is highly dependent on the spatial distribution of the existing transit network, and the distribution of income in the region (Ecola & Light, 2009). This is namely because highway tolls will negatively impact the ability for low income travelers to access destinations of work or other services (El-Geneidy, Buliung, et al., 2016). According to Small (1992) from an equity standpoint, the most direct way of distributing excess highway tolling revenue is to invest in alternative public transit options within the same corridor so that those paying into the toll are funding alternatives to driving. While multiple studies on congestion pricing in Europe have shown tolling and cordon policies to have a significant positive impact on public transit usage (Di Ciommo & Lucas, 2014; Eliasson, Hultkrantz, Nerhagen, & Rosqvist, 2009; Franklin, Eliasson, & Karlström, 2009), an important distinction in the North American context is that a much higher proportion of lower-income commuters are unable to rely on public transit to commute to work (Ecola & Light, 2009). Therefore, in studies that have found highway tolling policies and cordon pricing to be vertically equitable, there is always a strong emphasis on important differences in land-use patterns and income distribution within a given region (Kockelman & Lemp, 2011; Levinson, 2010).

Lump-sum redistribution, tax reduction and the issue of "double-taxation"

Two commonly competing schools of thought exist when discussing the potential monetary redistribution of funds collected through tolling or congestion pricing. Whereas one school prefers a monetary lump-sum distribution back to toll-payers, the other prefers to refund the impacted population via tax deductions (de Palma & Lindsey, 2007; Kockelman & Lemp, 2011). It is generally accepted that by redistributing funds to the impacted individuals as a monetary lump-sum, policy-makers can reverse the potentially inequitable impacts of the toll, making the policy progressive. While lower income groups often have less flexibility in their travel options and time-of-day, the sum distributed back to them it is expected to reverse this imbalance (Anderson & Mohring, 1996; Ecola & Light, 2009). Although lump-sum distribution is relatively easy to implement, it may not be politically feasible because it does not take into account the spatial differences within a region, nor the amount that individuals in different circumstances will use the roads. Therefore, by definition some groups will be benefiting at the expense of others.

A commonly argued point when it comes to highway tolling is from higher income groups who feel that they are being taxed twice to pay for infrastructure: once through their income taxes, and then again by paying a high proportion of the tolling revenue. For this reason, a commonly considered alternative to lump-sum distribution is income tax cuts for the affected population (Ecola & Light, 2009; Eliasson & Mattsson, 2006). This is considered a regressive policy because higher income groups would benefit disproportionately from a tax reduction when compared to lower income groups, thereby reversing the vertical equity intentions of the income tax system (Kockelman & Lemp, 2011). Proponents of income tax reduction argue that because higher-income groups tend to use tolled highways more due to high car ownership and a higher value of time, they should be compensated (Eliasson & Mattsson, 2006) (see the Stockholm example below). However, additional equity concerns exist because low-income groups may be priced out entirely from roadway use, to the benefit of those who can afford to pay to use the uncongested roads (Ecola & Light, 2009; Kockelman & Lemp, 2011).

Exemptions

In the cordon-pricing systems in Stockholm and London, exemptions have been implemented based on certain geographical limitations in the regions (Ecola & Light, 2009). In both cities, for example, disabled persons and residents living inside the zone do not need to pay the charge (Dix, 2005). Another type of exemption would be to allow low-income residents in a region to use the roadways at a reduced rate or even for free. However, it is important to note that when discounts are applied to a road pricing system, there will inevitably be a reduction in the amount of revenue generated by the mechanism. For instance, in the first few years of the cordon charge in London it was estimated that only 40% of all vehicles have paid the full cordon charge which significantly reduced the total revenue of the toll (Evans, 2007).

Credit-based congestion pricing

In order to alleviate the potential inequitable impacts of highway tolls and congestion pricing, Kockelman and Kalmanje (2005) propose a credit-based congestion pricing (CBCP) scheme. In the simplest form of this model, average roadway users do not pay for roadway use, while users who chose to use the roadways frequently and during peak periods subsidize others who don't use the roads at all (Kockelman & Lemp, 2011) Highway users would not pay tolls every time they use a given highway. Instead, at the end of a given period (e.g., annually) revenues would be distributed between users depending on their usage (Kockelman & Kalmanje, 2005). This system allows for marginal social cost (MSC) pricing in order to limit congestion on highways. Benefiting from the constant technological advances of tolling technologies, research has shown that CBCP has the potential to combat congestion while providing surplus funds that can be used by governing bodies to invest in alternatives, such as public transit infrastructure improvements (Chen & Nozick, 2016; Kockelman & Kalmanje, 2005).

No matter the type of redistribution of tolling revenue chosen, the literature demonstrates that revenue distribution may be the most powerful tool for balancing out the equity impacts of road pricing in a given region (Ecola & Light, 2009; Franklin et al., 2009; Levinson, 2010). Public transit infrastructure is considered a viable use of toll revenues that has also been proven to encourage a modal shift towards public transit use (Ecola & Light, 2009; Eliasson et al., 2009). Meanwhile, by simply investing in maintenance and expansion of highways, as has most often been the case in the United States, governments will not succeed in facilitating this transition away from single-occupancy vehicle use. Studies have found that while they may be equitable, if highways are widened for the creation of HOT lanes, as they often are in the US, they will simply induce demand for further highway expansion and urban sprawl (Patterson & Levinson, 2008).

For these systems to work, it is crucial that policy-makers are clear on the goals of road pricing. Though funds collected are likely to be used in the transportation budget, the charges are targeted as disincentive for driving during peak hours, rather than to fund necessary infrastructure maintenance. With the surplus collected through congestion pricing, Small (1992) suggests that revenue should be split between monetary reimbursement and transportation investment because it is unlikely to be politically acceptable to uniquely fund public transit. Smart investment in public transit projects that provide alternatives for those impacted by the tolls may be the most economically feasible option for North American cities to achieve goals of reducing time lost to traffic congestion without negatively impacting the environment. These investments can be made in parallel with highway maintenance spending and will have an impact on the largest portion of the current population (Ecola & Light, 2009). This blended approach to revenue investment may be the most realistic given the North American political and land-use context that varies significantly from congestion pricing models in European cities (Börjesson, Eliasson, Hugosson, & Brundell-Freij, 2012; Ecola & Light, 2009; Levinson, 2010).

2.3 Case Study: Cordon Pricing in Stockholm, Sweden

Congestion pricing in Stockholm, Sweden began with a year-long trial and adopted as a permanent policy in 2007 (Börjesson et al., 2012; Eliasson et al., 2009). This cordon-pricing scheme was heavily studied both before and after the trial, and is now considered to have fundamentally changed public opinion around congestion pricing in Stockholm (Eliasson et al., 2009). In summary, the policy to create a 30 km^2 toll zone with a population of 300 000 inhabitants was started as a trial in 2006 and was adopted permanently via referendum in early 2007. The trial was designed to educate residents of the Stockholm area on the benefits of congestion pricing before allowing them to vote on whether it would become a permanent policy (Eliasson & Mattsson, 2006). Research demonstrates that the policy has successfully reduced the number of kilometers driven within the city by 15% and travel times along major arterials have been reduced by up to one third. It is also estimated that CO_2 emissions have been reduced by 14% and emissions of other air pollutants have been reduced by 8.5-14%. Finally, public transit use increased by 4.5% following the implementation of the policy (Eliasson et al., 2009).

Studies from a social welfare and equity standpoint have proven to be similarly promising. Before the trial took place, Eliasson and Mattsson (2006) carried out a study predicting a net social welfare benefit from the cordon system. The most important factors influencing this expected outcome were the impact on initial travel patterns and the government's use of revenues. The study also predicted that the highest income groups would be the most impacted because they made more car trips than any other income group. Studies carried out since the implementation have confirmed the predicted net social benefit (Eliasson & Transek, n.d.), due in large part to the extensive public transit network already available in Stockholm. Commuters who would have otherwise crossed the cordon by car had a 15 percentage-point higher rate of switching to public transit, which was a viable alternative to driving (Karlström & Franklin, 2009).

Studies have looked at the equity impacts of Stockholm's cordon pricing model. Karlström & Franklin (2009) found that the lowest income group and the two highest income groups were negatively affected by the toll. However, Franklin et al. (2009) furthered this analysis by factoring in the redistribution of revenues, a key factor that was excluded from the Karlström & Franklin (2009) study. With the added benefit of a lump sum re-distribution of toll revenues to the entire population, the lowest income group gained the most and the highest group benefitted the least, though all groups experienced a net positive effect from the policy (Franklin et al., 2009).

2.4 Review of equity research in Toronto and the GTHA

Multiple studies have examined the distribution of income in the GTHA and the surrounding communities (El-Geneidy, Buliung, et al., 2016; Foth, Manaugh, & El-Geneidy, 2013; Hulchanski, 2010). In his pivotal work "The Three Cities within Toronto" Hulchanski identified a trend that since the 1970s, there has been increasing polarization in individual average incomes of the Census Tracts (CTs) in the City of Toronto. The study found that the number of middle-income CTs in Toronto was decreasing, while CTs with high or low-middle income (when compared to the regional average) were increasing in number. While the study focused on Toronto, the findings concluded that rather than middle-income groups simply re-locating to the outer suburbs, it was most likely that this polarization was occurring across the GTHA. As a result of this rapid change, sharp contrasts in income can now be observed across very small distances within the city in a way that was not observed 30 years ago (Hulchanski, 2010). These observations are also supported by other studies which have shown increasing concentration of income groups within Canadian cities (Ades Josefina, Apparicio Philippe, & Séguin Anne-Marie, 2012; Hajnal, 1995). These studies highlight that income distribution in the GTHA is constantly evolving, and that CT-level census geography is the most effective way of tracking these changes (Hulchanski, 2010).

Figure 2 illustrates the median after-tax household income of all of the census tracts (CTs) in the GTHA study area, with the lower- and middle-income CTs (below $60,000) shown in orange. It can be seen that many of these CTs are found throughout Toronto's inner suburbs, in Hamilton, and parts of southern Durham and Mississauga.

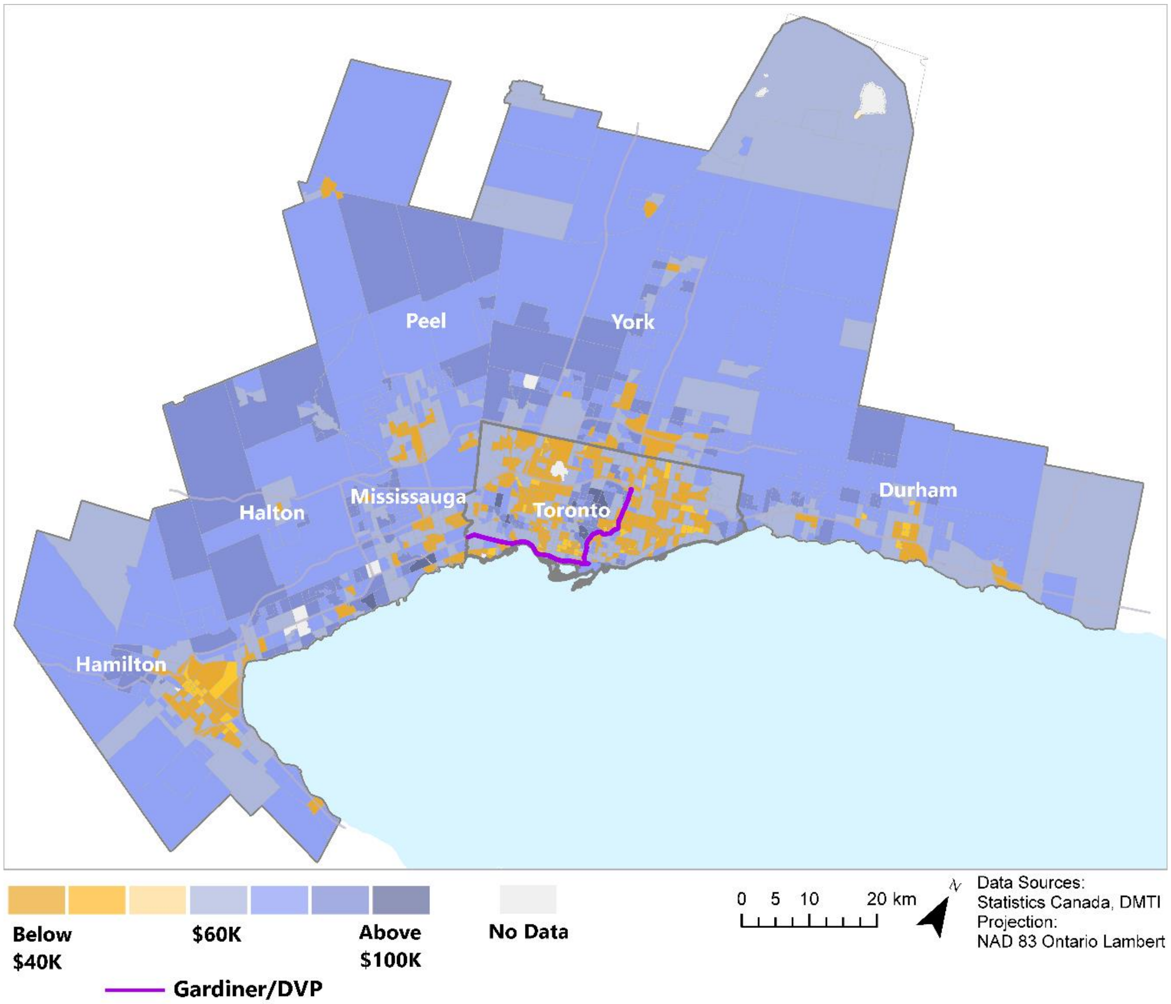

Figure 3. 2015 Median after-tax household income in the GTHA

2.4.1 Transit equity in the GTHA

The unbalanced spatial distribution of income in the GTHA has important implications on transportation policy such as highway tolling and the provisioning of public transit (Ecola & Light, 2009; Kockelman & Lemp, 2011; Levinson, 2010). International studies of equity demonstrate that when lower income groups have access to transit, highway tolling schemes can be seen as equitable. In the Stockholm example, a key distinction from North American cities is that many of the impacted areas outside of the city centre already had excellent access to transit before the trial began (Eliasson & Mattsson, 2006). Also, the income distribution in Stockholm is such that high-middle income earners tend to live in close proximity to the city centre, so more of their trips are impacted by the cordon pricing scheme (Börjesson et al., 2012).

In the GTHA and many other North American cities, income distribution is quite different than what is found in Stockholm, and low-middle income workers in Toronto are increasingly faced with two important obstacles (El-Geneidy, Levinson, et al., 2016; Hulchanski, 2010). The first is that neighbourhoods in the central city and/or with high transit accessibility to jobs have become increasingly inhabited by higher income groups. This trend raises housing prices in these neighbourhoods and does not allow for low-middle income groups to live in transit-accessible areas (Foth et al., 2013; Hulchanski, 2010). The other is that suburban areas in the GTHA are seeing increased job growth, especially for individuals in the lower-middle income groups (Hulchanski, 2010). These two factors, among others, have caused low-middle income individuals to relocate to areas that have very low transit access, and they may also be required to access jobs that are equally inaccessible by transit (Foth et al., 2013). These workers and their families have therefore become captive to driving as their only feasible option for access to jobs and other essential services. It is possible that these low-middle income earners may in fact see the largest financial impact from a highway tolling policy, due to their combination of distance from the city centre, minimal disposable income, and because they are captive to driving due to low public transit access.

Interestingly, while many lower-middle income groups have been found to have below-average access to jobs via public transit, equity studies in Toronto have found that the lowest income groups, or lowest decile when using social deprivation as a metric, tend to have high access to transit (El-Geneidy, Buliung, et al., 2016; Foth et al., 2013). This is due in part to the fact that lower income individuals are often seen as "captive riders" to transit, in that this is the only affordable option for these individuals to travel (Garrett & Taylor, 1999; Polzin, Chu, & Rey, 2000). These captive riders likely choose to locate themselves in areas with high access to transit, or may live in inner-city communities that have traditionally been low income. (Foth, Manaugh, & El-Geneidy, 2014; Foth et al., 2013).

This study aims to understand the income distribution of GTHA residents who use the DVP and/or Gardiner to commute to work. The impacts of a flat toll, such as what has been proposed by the City of Toronto, are highly dependant on regional and local context (Ecola & Light, 2009). Literature shows that lower income groups tend to feel the most impact of blanket tolling (i.e., charging a flat $2.00 to all users), because blanket tolling affects all income groups the same regardless of individual needs such as access to alternatives like public transit or un-tolled routes. However in most regions it is in fact higher-income travellers who drive more often and thus make up a larger proportion of those who are impacted (Eliasson et al., 2009). For these reasons, while the lowest income groups may attract more attention in the equity discussion around highway tolls, it is important to understand the distribution of all commuters who may be impacted by the policy, as this study aims to do.

3. METHODOLOGY

This study modelled the routes with the fastest travel time between home locations and work destinations for all work trips in the GTHA. Trips that used the Gardiner and/or DVP according to the model were then selected for further income analysis. Origin-destination data analyzed is at the 2016 Statistics Canada CT-level. These trips were modelled using network analysis in ESRI's ArcGIS software which was then joined with 2016 Statistics Canada home-to-work flow data (Statistics Canada, 2016). The model accounts for all commuters in the GTHA, but does not include trips for other purposes, or for commercial vehicle traffic that used the highways. The following sections describe the methods and data sources used for this analysis in greater detail.

3.1 Study area

This study will refer to the GTHA as the area delimited in figure 1 (see section 1.1). Slightly different limits for the GTHA were used than those that are officially recognized. Small sections of the municipalities of Dufferin and Simcoe were included at the northern boundary of the study area, and the rural townships of Scugog (pop. 21,617) and Brock (pop. 11,642) were excluded.

3.2 Personal income in the GTHA

The Statistics Canada commuter flows provide the origin and destination of the commuting trip along with *personal* before- and after-tax income for the employed labour force aged 15 years and over *having a "usual place of work"* (Government of Canada, 2017b). In this study, after-tax (rather than before-tax) income was chosen because it better reflects the impact of Canada's tax/transfer system, and because the purchase of necessities is made with after-tax dollars (Government of Canada, 2017a). The commuter flows data made available by Statistics Canada does not include household or economic family incomes, which means it is not possible to compare this data against the low income cut-offs (LICOs) established by Statistics Canada (Government of Canada, 2017a). For this reason, a comparison of the relative incomes of workers who commute using the Gardiner and DVP is important as it is the best way to evaluate the relative impacts of the potential tolling strategy on the GTHA working population with the given dataset.

It is also important to note that increasingly in the literature income is not the only variable that should be considered when evaluating poverty levels. It is for this reason that a social deprivation metric was established by Foth et al. (2013) and includes unemployment rate, recent immigrants and the percentage of households that spend 30% or more on rent. Ideally, rather than using income as a single determinant for commuters that are socially disadvantaged, this metric could provide other insights. However, such indicators are subjective and, in some cases, not well-understood by policymakers, so this study makes the income information more transparent. Further, the census commuter flow data does not include these socio-economic variables, thus making it challenging to go beyond a relative measure of personal income when comparing different groups in the GTHA.

The employed labour force in the GTHA study area was divided into personal after-tax income groups as shown in Table 1. This was done to both make it easier to differentiate between groups in the following sections, and to make it possible to make useful comparisons between the commuters who are impacted by the tolls and the entire commuting population.

Table 1. Income group classification by personal after-tax income in the GTHA

GTHA income group	After-tax personal income	Generalized name
Low	Below $20 000	"Lower-income"
Low-middle	$20 000 - $40 000	
Middle	$40 000 - $60 000	"Middle-income"
High-middle	$60 000 - $80 000	"Higher-income"
High	$80 000 and above	

3.3 Determining Origin-Destination Pairs

The Statistics Canada data includes home and work CTs of all workers in Canada. This dataset also includes the before- and after-tax personal incomes of workers making each trip in $5K or $10K increments, so it is possible to match a work trip to the personal income of the individual making the trip. Trips made by less than 10 people in any income bracket are excluded from the dataset, which creates data suppression issues which may have slightly skewed the results. Data suppression has a greater impact on the income data because groups of less than 10 in an individual income bracket making a particular trip are also excluded. Data presented without income levels is likely a more accurate representation of the actual situation, while income levels should be used more for relative purposes. This study generated routes for over 300,000 potential CT-to-CT work trips within the GTHA using a combination of ArcGIS Network Analyst and R. Many of these routes represent CT-to-CT trips taken by more than one worker, resulting in a total of 2.8 million GTHA workers represented in the data (table 3).

3.4 Network Analysis

Figure 4 illustrates the methodology used to model all work trips in the GTHA. First, a shapefile including all streets and highways in the GTHA was used to generate a time-distance network. This street network included free-flow travel-time estimates based on the speed limit and length of all street sections. Travel-time was set as the impedance for the network and routes were modelled by shortest travel-time between origin and destination. It is important to note that because the network does not include potential congestion that will be encountered by drivers, the actual travel-time of the routes will be underestimated by the model.

Next, the route analysis tool was used to map out the paths taken between the centroids of each origin and destination CT for each work trip[1]. Figure 4 shows a sample of the output of the route analysis: two routes that connect home and work CTs across the GTHA using the most time-effective paths. A worker on Route A (orange), travels along the entire length of the Gardiner Expressway in order to reach his destination. A driver on Route B (blue), meanwhile, does not require either the Gardiner or the DVP to access his work destination. Finally, a worker uses “alternate route” Route A (dashed orange) when the network restricts the use of Gardiner and DVP, which mimics their route when choosing to avoid the toll. Although the alternate routes used by workers were not used in this analysis, they would be useful studies that examine potential travel-time impacts and traffic in neighbouring communities. All CT-to-CT work routes travelled by car in the GTHA (n = 305,135) were modelled in this way, whether they used the Gardiner/DVP or not. These routes were then intersected with a shapefile of the Gardiner/DVP and all other work trips were excluded from the remainder of the study. The resulting data set (n = 68,452) includes all CT-to-CT routes that will be impacted by the toll.

[1] Note: Although ArcGIS provides an “Origin-Destination (OD) Matrix” tool in the Network Analyst Toolbox, it was not possible to use this tool for this analysis because the output of OD-Matrix tool does not include the exact route taken to complete each trip.

Figure 4. Sample output of network analysis

Table 2 provides example travel-times and distances calculated in network analysis for the above example. Route A is 41.7 km when using the Gardiner, versus 41.6 km when the Gardiner is avoided. This shows that the model successfully followed the fastest route, even when it was not the shortest. The intersect also made it possible to calculate the distance that each trip used the Gardiner/DVP. Modeled routes that used less than 900m on either the Gardiner or the DVP were excluded because it is the minimum distance between highway exits. Although the model predicted these trips would use the highway, it is unlikely that commuters would chose to get on the highways for only one exit. All trips that used either the Gardiner or the DVP for at least 900m were considered equally impacted by the policy (i.e. additional impacts were not attributed to distance). The importance of this assumption is highly dependent on whether the toll chosen is a flat rate or distance-dependant, but since the initial proposal indicates the potential for a flat toll, this simplification should be appropriate for this diagnostic study.

Table 2. Summary of travel-times and distances for sample routes

Route	Distance (km)	Highway Distance (km)	Free Flow Travel Time (min)
Route A	41.7	18.5	31.1
Route A (avoids toll)	41.6	N/A	36.7
Route B	50.9	0	32.3

3.5 Income Analysis

The 2016 Statistics Canada data includes the after-tax income bracket (at $5K intervals), mode, and home and work destinations of all workers in Canada (Statistics Canada, 2016). This dataset is structured such that the total number of workers in each income bracket completing any of the possible CT-to-CT trips is tabulated according to the income and mode choice of the travellers making each trip. The data is further divided between all commuters who get to work by car, either as drivers or passengers. This analysis included both drivers and passengers as all will be impacted by the potential toll. This data was then joined with the routes generated by the network analysis and intersect described above to establish the number and income breakdown of all workers driving on the Gardiner/DVP. The resulting dataset includes the total distance, free-flow travel time, and income breakdown of all drivers and passengers using the Gardiner/DVP to get to work. The 9:00 a.m. congested travel times is also available for a large proportion of the trips. Though not used in the present analysis, this information could support future modelling of the network impacts and benefits of the toll.

Due to the sheer number of trips established by the network analysis, this dataset is large so it was first aggregated by origin CT using R. The aggregated dataset provides the number and income breakdown of all workers using the Gardiner/DVP that live in each CT, independently of place of work. Of the 1436 CTs in the study area, 1426 contained workers who made trips that were recorded in the census. The other 10 CTs were excluded because they either did not have enough residents, or there were not enough trips originating in these CTs that used the Gardiner/DVP to meet Statistics Canada's data-suppression requirements. While it would also be interesting to look at the destinations of the workers using these highways, this simplification was done to shed light on the central research question, which is to establish the income breakdown and spatial distribution of impacted workers based on home location.

Income data for workers travelling on the Gardiner/DVP was aggregated over the whole study area, at the municipal level, and finally at the CT-level. These groups aim to help understand if there are important spatial differences in how commuters will be impacted by the tolling policy. Inequity in the spatial distribution of impacted workers could help to understand the best ways to mitigate negative outcomes of the tolling policy (Ecola & Light, 2009; Kockelman & Lemp, 2011; Levinson, 2010). This aggregated data was analyzed according to the income groups in section 3.2. The following section presents the results of the network analysis, beginning with the study area as a whole.

4. RESULTS

4.1 GTHA impacts

Table 3 provides the total number and income breakdown of all workers impacted by the Gardiner/DVP tolls in the GTHA. According to the model, out of a total of 2.76 million workers in the GTHA, 183,700 workers are impacted (6.6%). Within the impacted group, 47,900 are in the low-middle personal income bracket (26% of all impacted), followed by 43,000 in the highest income bracket (24% of all impacted). The lowest personal income bracket, those making below $20K, has 20,500 impacted workers, which represents the smallest group (11% of all impacted). However, it is important to ask to what extent this distribution of income among impacted workers is different from the distribution of income in the working population as a whole. The last column of Table 4 also shows that the income bracket with the highest percentage of workers impacted are those making over $80K (11.4%), and the lowest percentage are those in the lowest income bracket making under $20K (3.5%). This shows that, independent of the number of people in the general population in each income group, the likelihood of a worker being impacted by the toll increases with their income.

Table 3. Summary of impacted workers in the GTHA

Annual personal after-tax income	Number of impacted workers	Number of workers in GTHA	% of all impacted workers	% of income bracket impacted
Under $20,000	20500	574600	11.2	3.5
$20,000 – 40,000	35300	753900	19.2	4.7
$40,000 – $60,000	47900	667300	26.1	7.2
$60,000 - $80,000	35900	395700	19.5	9.1
Over $80,000	43000	376300	23.4	11.4
TOTAL	**183700**	**2767800**	**100**	**6.6**

Figure 5 compares the percentage breakdown of impacted workers against the income breakdown of all workers in the GTHA. The low-income (making below $40K) group represents nearly half (48%) of all GTHA workers, yet the same group represents only 30% of the impacted workers. The percentage of impacted workers in the low-middle income group (26%) is fairly representative of all low-middle income workers in the GTHA (24%). Finally, higher-income workers show the opposite trend of the low-income workers, as 43% of all workers using the Gardiner/DVP make $60K or more, yet only 28% of all GTHA workers surpass this income level. In other words, compared to the income distribution as a whole, workers expected to be impacted by the toll have disproportionately higher personal incomes.

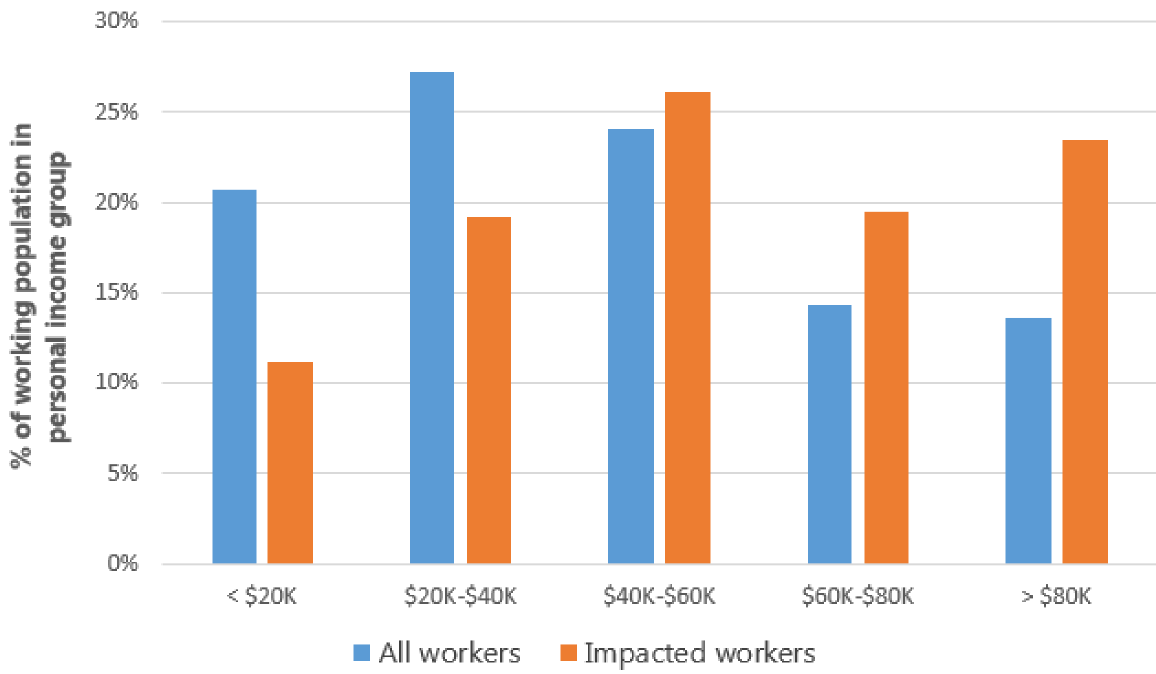

Figure 5. Income breakdown of all workers and impacted workers residing in the GTHA

4.2 Impacts by GTHA municipality

Figure 1 (see section 3) shows the GTHA study area when divided by upper-tier municipality. This grouping allows for analysis of the potential impact of the tolling policy on different regions within the GTHA. The cities of Toronto and Hamilton do not belong to an upper-tier municipality, while Mississauga was grouped separately from the Region of Peel for an improved understanding of potential impacts directly west of the end of the Gardiner. Small portions of Niagara, Simcoe and Dufferin that have been included in the study will be listed as "Other" in the following summary figures.

Figure 6 provides the breakdown of all impacted workers by region. Toronto residents are the majority of all impacted residents (63% of all impacted), with residents from York (11%) and Mississauga (9%) representing the next most impacted groups.

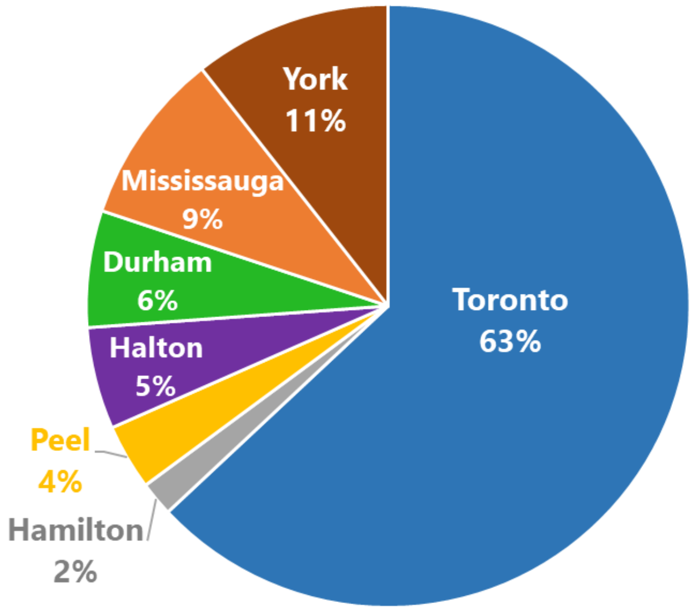

Figure 6. Impacted workers by municipality of residence.

Figure 7 compares the income breakdown of those living in the City of Toronto to the remainder of the GTHA. It shows that all of Toronto's income groups are more impacted than the same groups in the remainder of the GTHA in absolute terms. In both cases the low-middle income group (in grey, $40-60K) is the most impacted by the policy. In general, the income breakdown of impacted workers in the City of Toronto follows a similar trend to that of the remaining GTHA municipalities. However, one notable difference is that in Toronto the number of workers in the $20K - $40K income group surpasses those in the $60K - $80K group. The reverse is true in the remaining GTHA, where more $60K - $80K earners are impacted than workers in the $20K - $40K bracket.

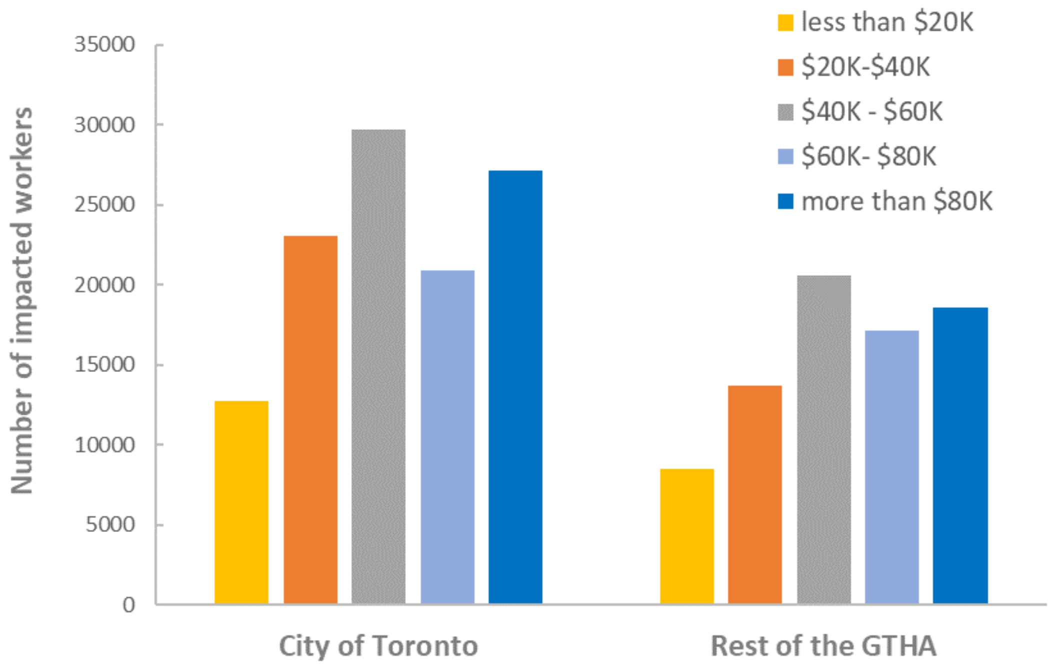

Figure 7. Number of impacted workers in residing in Toronto and in the rest of the GTHA

Finally, for more clarity on the impacts felt in surrounding municipalities, figure 8 shows the total number of impacted workers in the surrounding municipalities with Toronto removed. Low-middle income workers (in grey) are the most impacted in the majority of the municipalities. Higher income groups are also generally more impacted than lower income groups. In Halton, impacts are skewed towards the highest income group, and high-income groups in Durham and York are also significantly affected. In Peel and Mississauga, the distribution of income groups impacted is more normally spread across the community on either side of the most impacted low-middle income group.

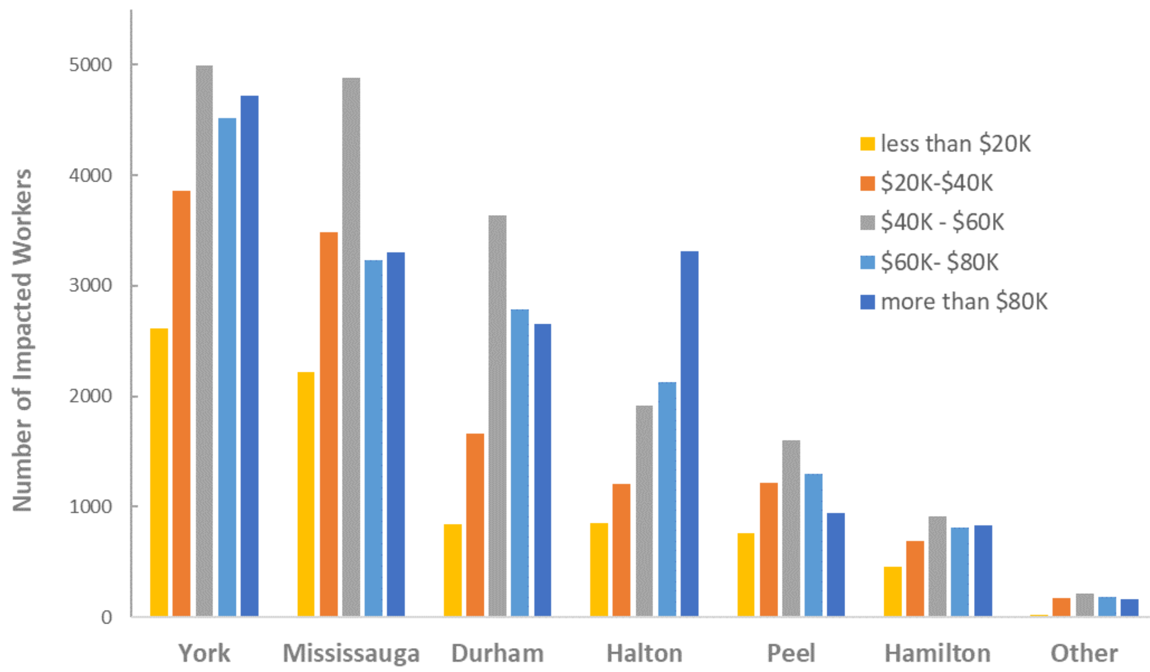

Figure 8. Number of impacted workers by income group GTHA municipalities outside of Toronto

Caution must be used when analyzing figures 7 and 8 as it is likely that distribution of those impacted is representative for the entire population. For this reason, similar to figure 6, figures 9a and 9b compare the income breakdowns of impacted workers to the incomes of all workers in the City of Toronto and the remaining GTHA, respectively. The figures show that there is very little difference between the City of Toronto and the surrounding populations. In both cases, the lower income groups are less represented in the impacted population compared to the general working population, while the higher income groups are more impacted by the tolls. This imbalance is more pronounced in the GTHA municipalities outside of Toronto than in Toronto itself.

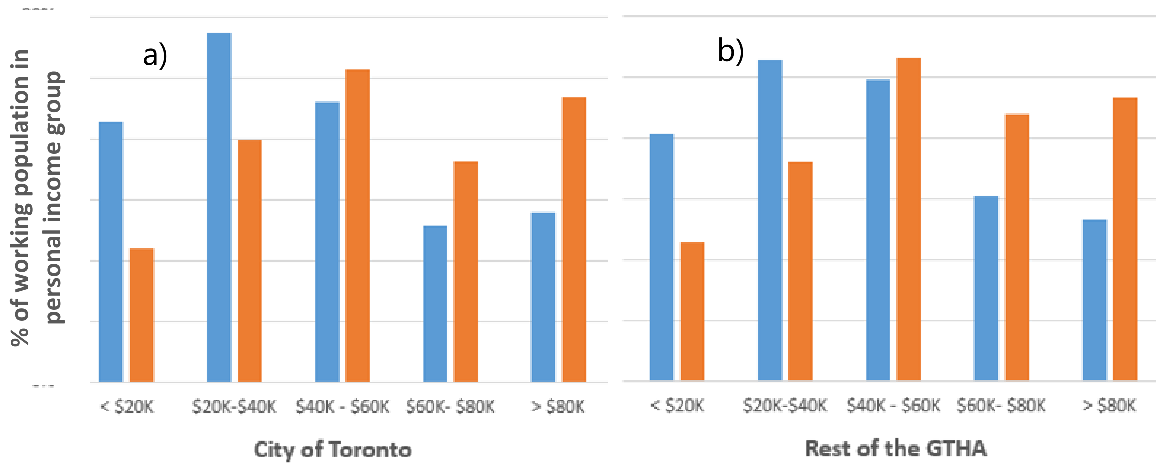

Figure 9. Income breakdown of all workers and impacted workers residing in Toronto (a) and the rest of the GTHA (b)

4.3 Impacts by census tract

Results at the CT-level have the best potential for understanding the spatial variations of the impact of the proposed highway toll policy. This is because the CT-level is the smallest unit of census geography where all socio-economic information is made available. Also, census geography is organized such that each CT contains between 2,500 and 8,000 persons. This makes it possible to compare absolute numbers of persons within a given characteristic (e.g. income) across multiple CTs in a region. The following figures aim to develop a better understanding of areas in the GTHA where workers are most impacted by the policy, and where potential interventions should be focussed. The figures should be used to analyze trends in the data, rather than the actual values themselves.

Figure 10 shows the percentage of workers in all of the GTHA using cars, either as drivers or passengers to access their work location. This figure does not reflect whether or not these workers rely on the Gardiner or DVP, but the highways are shown in purple for spatial reference. Across the GTHA, according to the census data, 69% of workers commute to work by car, and over 1000 of the 1426 CTs in the study area have at least 60% of workers driving to work. This proportion increases with distance from populated centres with more employment such as central Toronto, Mississauga and Hamilton. In the more rural areas outside of the urban core it is not unusual to observe CTs where over 80% of workers travel to work by car, shown in orange.

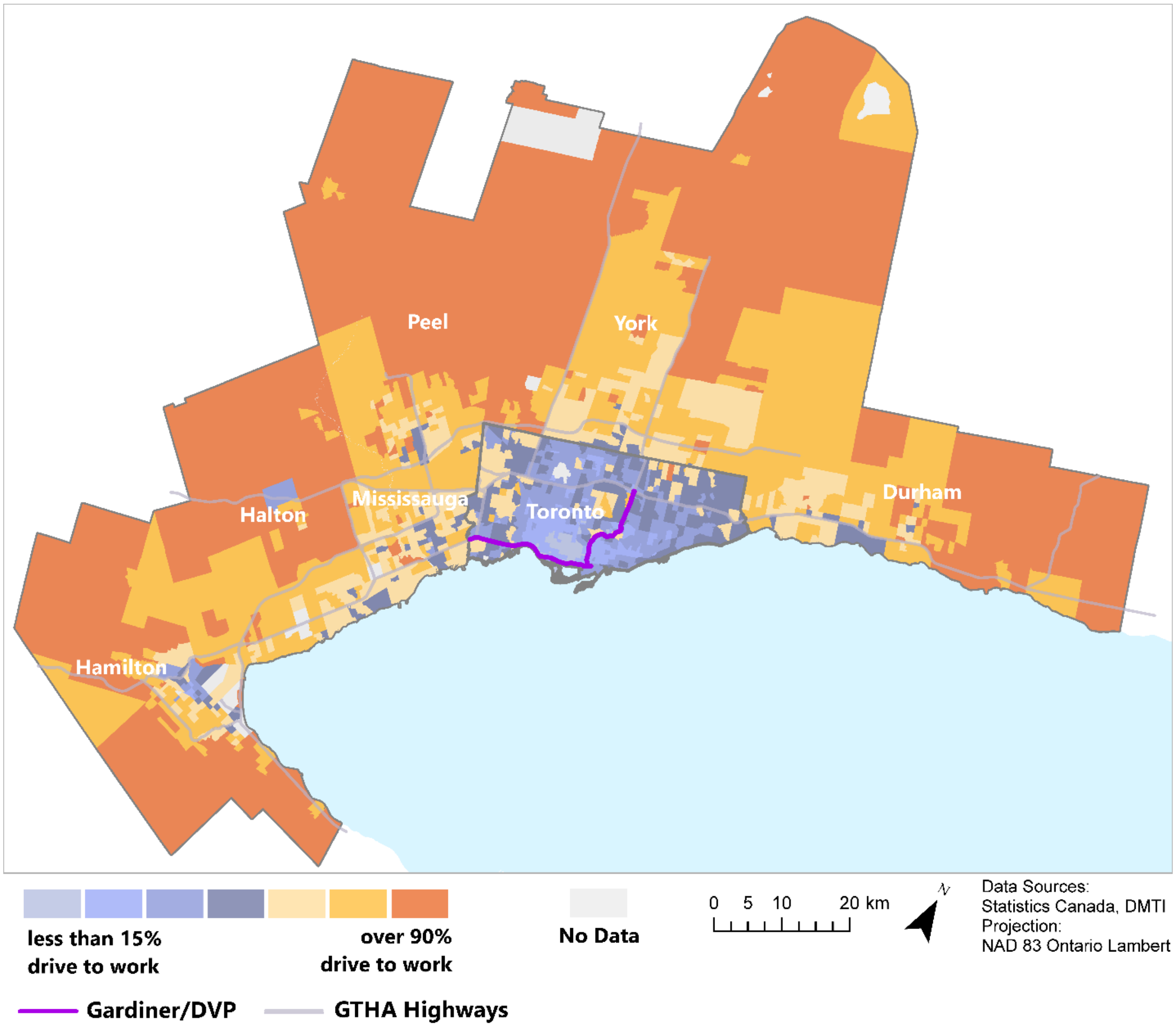

Figure 10. Percentage of GTHA workers who travel by car (drivers and passengers)

Figure 11 shows the percentage of workers who live in each CT and use the Gardiner/DVP to commute to work. In areas in grey, less than 5% of all workers will be affected by the policy, so they are not shown in the following figures. The policy impacts CTs closer to the highways in Toronto (in orange and red) than in the surrounding areas. There are some exceptions, however, such as in Mississauga and York, where the percentage of impacted workers exceeds 20% in some cases. Nonetheless, the clear trend is that of the CTs that are over 20% impacted, the majority are in Toronto. These populations are concentrated in far western inner suburbs (Etobicoke) and in areas around the DVP in eastern Toronto. It is perhaps not a surprising finding that the most impacted populations are in proximity to the highways, but this couldn't be assumed without modelling travel to and from work. Past efforts to study impact, for example by the City of Toronto, have simply assumed that the most impacted populations are in proximity to the tolled highways.

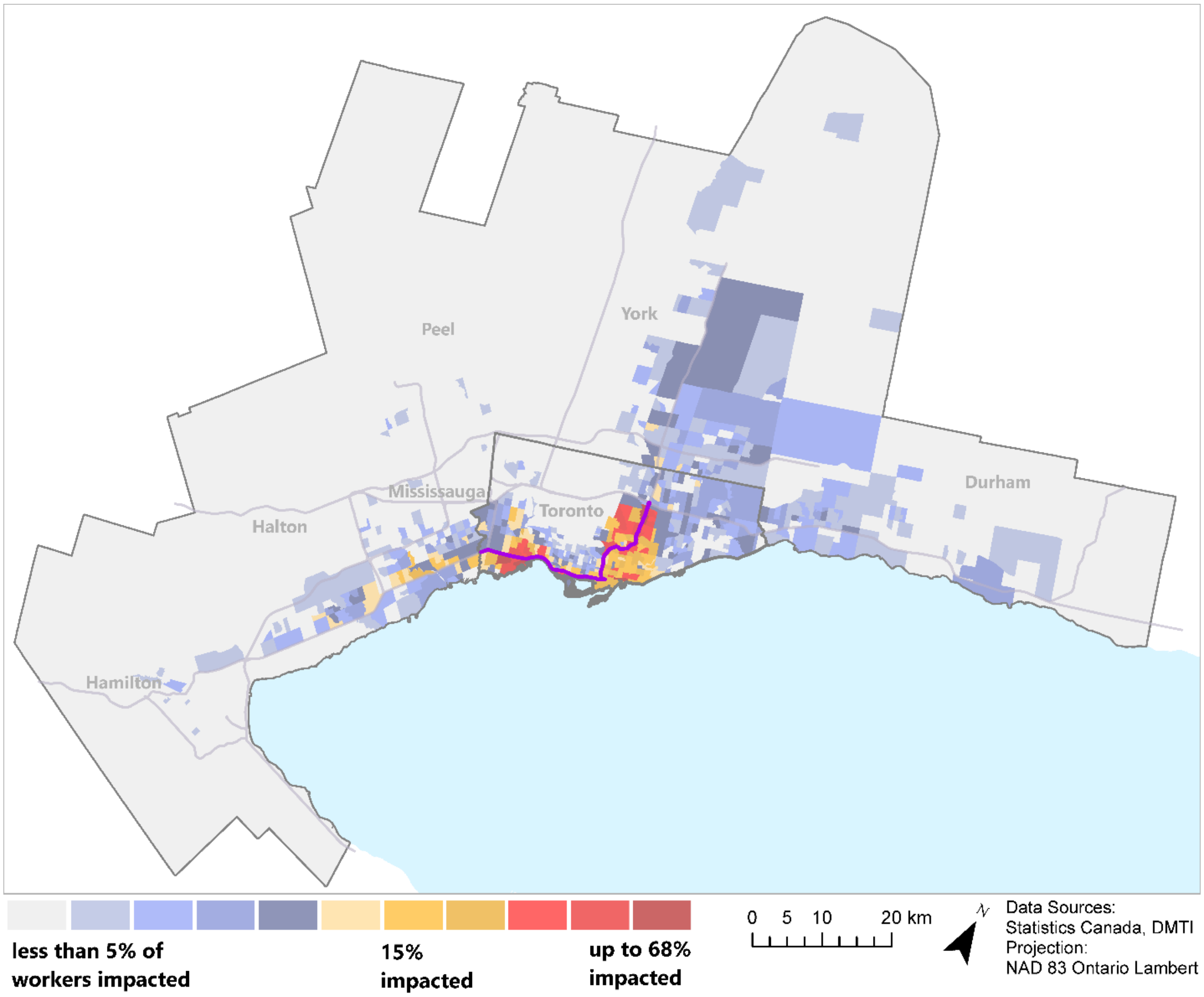

Figure 11. Percentage of workers impacted by home census tract

While the percentages of all workers impacted are important to look at, figure 11 does not include any information about the income levels of those who are living in the highly impacted areas. Figures 12a, 12b and 12c show the absolute number of workers who make under $40K, $40K to $60K, and above $60K in the CTs where at least 5% of workers are impacted by the policy. While the patterns in all three figures follow a similar trend to figure 11 some potentially important differences exist. First, in figure 12a it can be seen that although impacted areas of far eastern Toronto, York and Mississauga did not garner much attention when looking at the data as a percentage of all workers impacted, there are important populations of 200 or more low-income workers (in red) that are impacted in these CTs. Also, the clustering of low-income workers who are impacted south of the Gardiner in western Toronto and east of the DVP does not follow the same pattern as figure 11. These pockets of low-income workers lie in areas further from central Toronto.

In figure 12b, CTs with a high number of low-middle income workers show a similar pattern to the general distribution of impacted workers. Many of the CTs with more than 200 low-middle income workers are similar to those highlighted in figure 12a, but there are also more north of the Gardiner and west of the DVP. Also, there are fewer CTs in the middle (orange) range that have around 75 persons impacted than was seen in figure 12a, especially in eastern Toronto, Mississauga and York. In general, the impacted low-middle income earners are clustered closer to the highways, with small pockets scattered elsewhere in the study area.

Figure 12c shows the absolute numbers of higher-income workers with incomes above $60K. Notably, this map contains significantly more moderate-high impact areas than figures 12a and 12b. This is largely reflective of the fact that this map represents a larger proportion of all impacted workers (48%) than figures 12a and 12b (30% and 26% respectively). Additionally, much like what was seen in figure 12a, this higher-income population is much more dispersed around the study area than those in the middle-income bracket. While the typical high-impact areas close to the Gardiner/DVP also contain many high-income earners, now much of Mississauga, North York and western Durham are also significantly impacted. It is also the case that the areas closer to central Toronto that saw minimal impacts in other income ranges have more high-income earners that are impacted. Finally, the opposite is true for eastern Toronto, where it was previously seen in figure 12a that many low-income workers were impacted, fewer high-income workers are being potentially impacted by the policy.

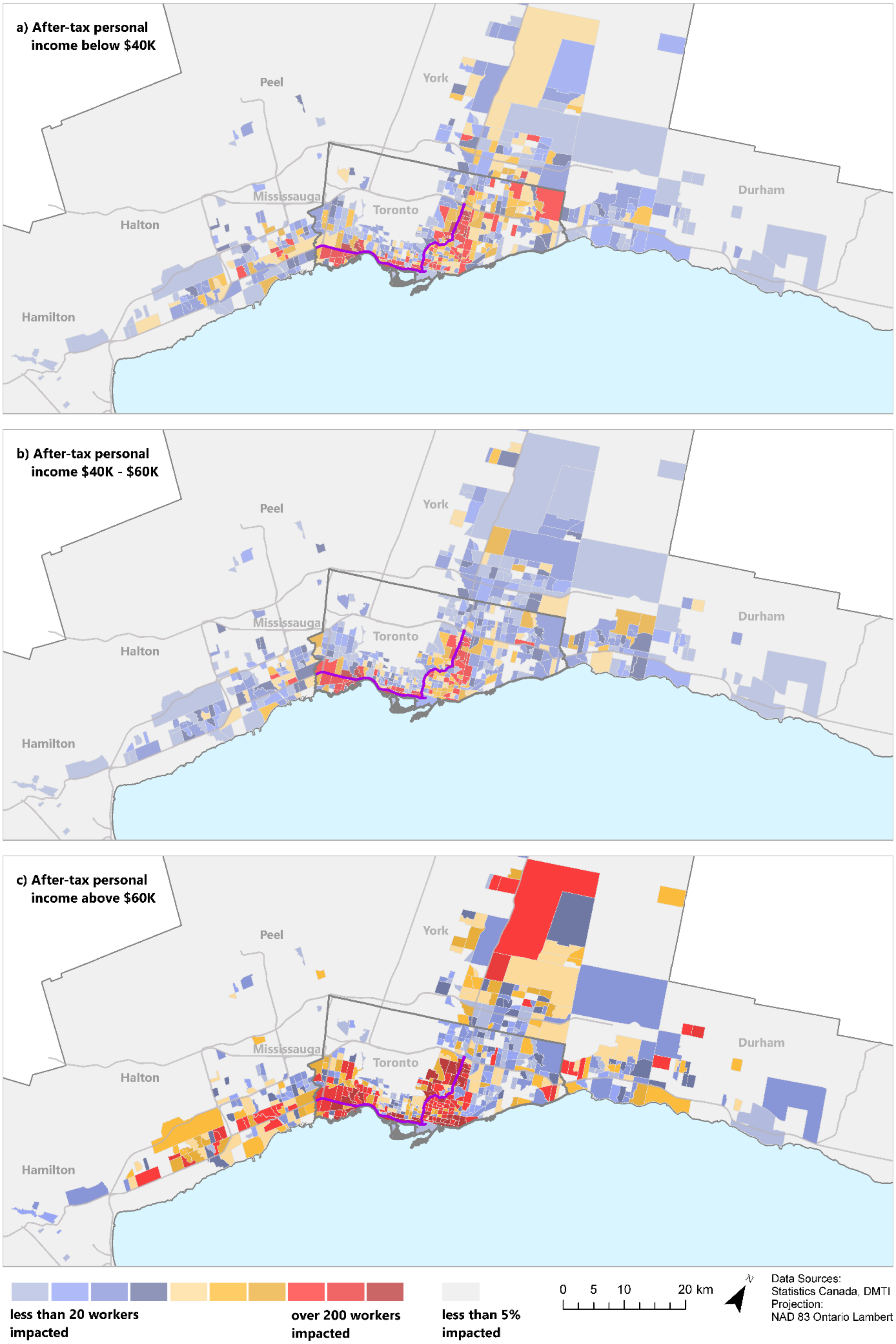

Figure 12. Total number of workers impacted in each CT by income group

Figure 13 illustrates the ratio of low- and low-middle income workers to middle- and high-income workers. It also includes the Toronto Subway lines and GO Transit rail lines to provide an understanding of the areas which are well-serviced by rapid transit in the GTHA. CTs with a majority of Gardiner/ DVP workers with incomes below $60K are shown in orange, while if the majority of workers make above $60K in a CT, it is shown in blue. An income threshold of $60K was chosen because it is the cut-off between lower- and higher-income workers in the GTHA used in our analysis. Also, 56% of impacted workers make below $60K, with the remaining 44% making above $60K. If the income distribution of impacted workers was uniform across the GTHA it would be expected that the orange and blue on this map would be scattered evenly throughout the GTHA, but this is not the case.

It can be seen that there are three spatially-separated populations that are being impacted by the toll. One group is the high-income workers in central Toronto, north of the Gardiner and west of the DVP. The second is comprised of the lower-income CTs closer to the Gardiner and in eastern Mississauga along with the CTs east of the DVP towards Scarborough and into western Durham. This cluster of lower income CTs is more pronounced in the eastern inner suburbs than in the west. The third group, also of higher-income workers, is found in a ring well-beyond the Toronto city limits. In the west, there is a majority of higher income impacted workers in western Mississauga and southern Halton, and in the north and east these workers reside in central York and eastern Durham. While this contrast appears rather stark, it is also important to note that the CTs further from central Toronto are much larger and the population density is lower. Large swaths of blue and orange represent significantly fewer people than the much denser populations closer to the highways. Although there are exceptions to this pattern (e.g. inner-city low-income CTs in central Toronto), this figure illustrates that clearly the spatial impacts of the tolling policy are not uniform.

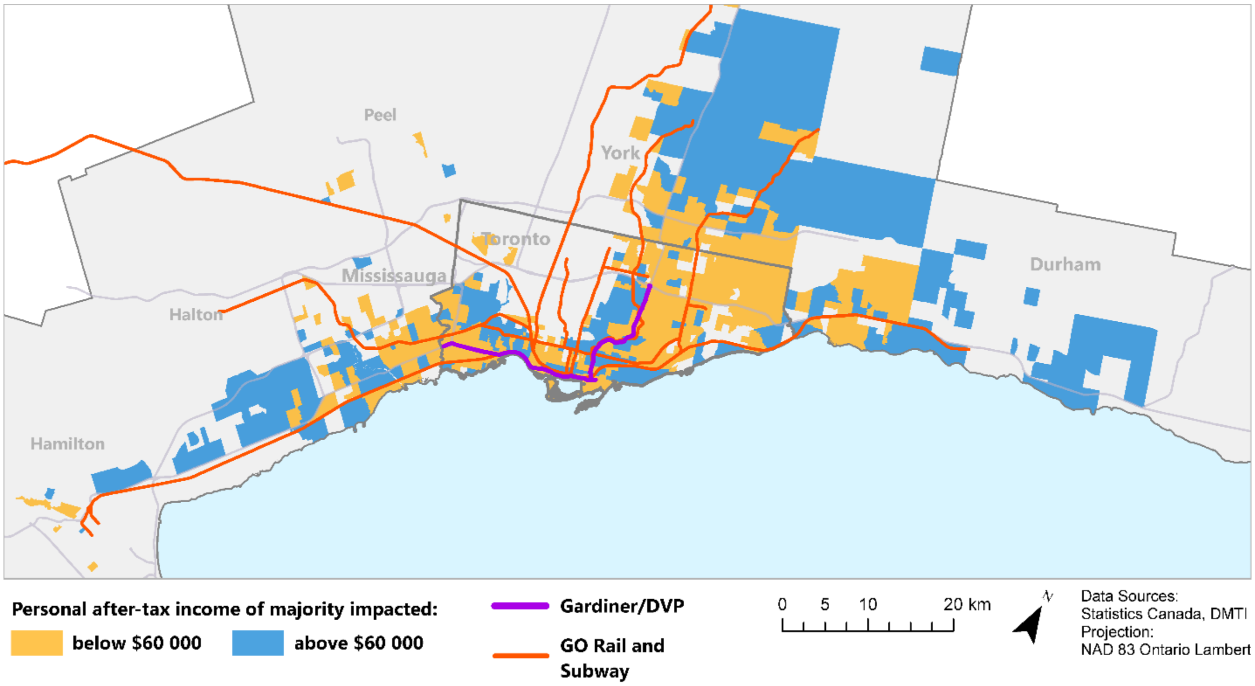

Figure 13. Ratio of lower- to higher-income workers by CT of residence

5. DISCUSSION AND RECOMMENDATIONS

Past studies have shown that before adding a toll to a highway that was previously un-tolled, it is crucial for policy-makers to have an understanding of the existing income breakdown and spatial distribution of the potentially impacted population (Ecola & Light, 2009; Levinson, 2010; Small, 1992). Multiple studies have also examined the distribution of income and socially disadvantaged groups in the GTHA (El-Geneidy, Buliung, et al., 2016, p.; Foth et al., 2013; Hulchanski, 2010), but none of these studies focussed directly on the potential impacts of highway tolls on users of the Gardiner Expressway and Don Valley Parkway. Although the City of Toronto has commissioned a study on the income-distribution of CTs adjacent to the Gardiner/DVP (City of Toronto, 2015), the City's work has not yet been released, and this present study has expanded on previous work to understand potential impacts in Toronto and adjacent GTHA municipalities.

The network-analysis model found that a total of 183,700 workers used the Gardiner/DVP to access work on a daily basis in 2015. This value amounts to 367,400 one-way work trips per day and is consistent with Gardiner and DVP cordon counts from 2011 that estimated approximately 520,000 one-way trips for all purposes (City of Toronto, 2011). This model also shows that workers in the City of Toronto itself will be the most heavily impacted by the tolls. Meanwhile the 37% of all impacted workers from the surrounding GTHA falls short of the 40% estimated by politicians and in the media during the debate over the toll (Lupton & Janus, 2016; Riva, 2016). Middle- and high-income workers making above $60K will also be proportionately more impacted by the tolls than workers making less than $40K. This finding was consistent across all of the working populations, both in the City of Toronto and in the remaining GTHA. Research on both cordon pricing in Europe (Di Ciommo & Lucas, 2014; Franklin et al., 2009) and highway tolls in North America (Anderson & Mohring, 1996; Nakamura & Kockelman, 2002) have yielded similar results. This is because higher-income workers tend to drive more than low-income populations, and they place a higher value on their time (Ecola & Light, 2009; Kockelman & Lemp, 2011). Meanwhile, low-income populations are more likely to be captive to other modes of transportation such as public transit (El-Geneidy, Buliung, et al., 2016; Foth et al., 2013). It follows that if the tolling policy is put into effect, these higher income populations will be more likely to pay the toll, and the highways will continue to be used more by high-income earners.

In terms of vertical equity, this disproportionate impact on higher income earners may be viewed as a progressive strategy for funding the maintenance of the highways and public transit (Ecola & Light, 2009; Levinson, 2010). However, it is important to note that a large number of low-middle income workers, making $40K to $60K will also be impacted by the policy. While these workers are not disproportionately impacted (% impacted is similar to the general working population), the prospect of having to pay a toll may be difficult for them. They also may not be willing or able to change their mode of transportation (Foth et al., 2014). Although low-income workers, making below $40K, are under-represented in the impacted population, many drivers in this group are also likely to be captive, and thus will be forced to pay the toll, or to change their routes to work. This means that while the toll may impact a larger proportion of higher-income workers, attention must also be paid to both the financial and marginal social cost inflicted on low and low-middle income workers in the population (Kockelman & Lemp, 2011; Levinson, 2010).

Analysis at the CT-level sheds further light on the spatial distribution of the workers who will likely have to pay to use the Gardiner or DVP. Multiple equity studies have focussed a significant amount of attention on the distribution of these impacts. This research has concluded that for a tolling policy to be equitable, impacted drivers must have an alternative to using the highways such as public transit or an alternate non-tolled route (Ecola & Light, 2009; Eliasson & Mattsson, 2006; Levinson, 2010). However, Foth et al. (2013) identified that within the limits of the GTHA rapid transit network, there are areas with poor transit accessibility, many of which correspond to CTs that will be highly impacted by the Gardiner/DVP tolls. This study has identified pockets of workers in all income ranges that will be impacted should the tolls be implemented. From an equity perspective, areas with pockets of lower-income workers may require the most attention as it is here that alternative options will be most relevant. For example, while there are pockets of middle- and high-income workers in Mississauga and Halton, there are many more low-income workers being impacted east of the DVP in the inner suburbs of Toronto. Research has shown that the high-income groups will likely continue to use the highways at minimal financial impact once the toll has been implemented, while lower-income groups will be forced to seek out alternatives (Anderson & Mohring, 1996; Ecola & Light, 2009; Eliasson et al., 2009).

5.1 Recommendations

The City of Toronto has proposed a fairly simple tolling structure of either a flat toll for all users of the Gardiner/DVP, or a distance-based model where drivers are charged per km of highway driven (City of Toronto, 2015). Although it may be tempting for politicians to opt for a basic policy such as a flat toll, research has shown that this system will likely have negative equity impacts (Ecola & Light, 2009; Kockelman & Lemp, 2011; Levinson, 2010). These effects will be further amplified because the income distribution is not uniform across Toronto and the GTHA. The following set of recommendations are based on the income and spatial distribution of potentially impacted workers in the GTHA. The region-specific data in this study is compared against best practices in road pricing from North America and around the globe. While road pricing is a relatively new concept in the GTHA, and in Canada as a whole, the above research suggests that if done with the specific goals in mind of funding infrastructure improvements and reducing congestion, it can be successful. To achieve these goals, this study proposes the following:

1) **Explore options for public transit improvements and other forms of toll revenue redistribution, especially for residents with low access to transit options.** Compare the income distribution from this study to future GTHA public transit plans and identify areas where public transit improvements will most effectively provide alternatives to low-income drivers currently captive to the targeted highway infrastructure. Additionally, while public transit improvements will serve a long-term goal of encouraging a modal shift away from driving, in a North American city such as Toronto, they will do little to alleviate the short-term equity impacts of the Gardiner/DVP toll (Ecola & Light, 2009; Small, 1992). In the interim, careful

consideration must also be paid to other types of investments. Other redistribution could come in the form of a monetary lump-sum distribution to toll-payers who have limited transit access, especially as the GTHA works to fill the public transit gap that currently exists (El-Geneidy, Buliung, et al., 2016; Metrolinx, 2018).

2) **Invest in road pricing infrastructure that will allow for variable tolling options, such as distance- and time-based pricing.** At minimum, a distance-based toll will allow drivers to be charged based on the distance travelled with the potential to adjust for other factors, such as time of day and type of vehicle used. In the future, this technology could be used to facilitate more complex tolling strategy, such as credit-based congestion pricing (Kockelman & Kalmanje, 2005). This could be used to re-distribute tolling revenues and to help account for the marginal social cost of congestion in the GTHA.

3) **Re-purpose existing highway lanes as High Occupancy Toll (HOT) lanes.** An equitable option that will not negatively impact the environment may be to re-purpose existing lanes on the Gardiner and DVP to create High Occupancy Toll (HOT) lanes. HOT lanes have been proven to be politically feasible in multiple North American cities, as they maintain an un-tolled option for commuters who are unable to or prefer not to pay the highway toll. These HOT lanes should not come in the form of highway expansion as this will do little to prevent long-term congestion problems and may induce increased urban sprawl in the GTHA region (Patterson & Levinson, 2008).

4) **Conduct a pilot project and evaluate the actual impacts of the chosen road pricing strategy on the population.** In the highly successful Stockholm cordon pricing example studied, a crucial aspect to public acceptance was a trial period (Eliasson & Mattsson, 2006; Franklin et al., 2009). This type of trial has also been done on the QEW in the GTHA, and has been shown to help impacted residents better understand how they will be directly affected by the toll. It also gives researchers an opportunity to evaluate economic, equity and congestion impacts of the proposed policy.

6. CONCLUSION

Road pricing can be an effective method for raising funds for highway maintenance and public transit investment (Ecola & Light, 2009; Levinson, 2010; Litman, 2006). The funds raised from a highway toll can be used in addition to, or as an alternative to, other taxation such as income tax and fuel tax, and to help balance out equity issues in urban regions (Venter & Joubert, 2014). However, every region is different, and it is crucial to understand the spatial destitution and income breakdown of a region before a road pricing scheme is implemented.

This study has used current census data and ArcGIS network analysis to evaluate the potential impacts of roadway pricing proposed by the City of Toronto on the Gardiner Expressway and DVP. This evaluation goes beyond the city limits of Toronto to estimate how the entire GTHA region may be impacted by this policy. The study found that higher-income workers are disproportionately impacted by the tolls, while lower-income communities are under-represented among the impacted population compared to the general population. While they are not disproportionately impacted, so-to-speak, low-middle income workers represent the largest total number of impacted workers in the study area. The spatial distribution of workers in different income brackets is not uniform. Pockets of lower income workers that use the Gardiner/DVP can be found throughout the study area, and notable clusters exist in Toronto's inner suburbs, western Mississauga and York. Meanwhile, higher-income impacted workers tend to live either closer to the city centre, or in the far outer suburbs. Although lower-income workers are under-represented in the data, there is still a considerable number of workers earning less than $40K that are using these roads to get to work. Mitigating the potential impacts of the toll on these workers is important because many of them live in parts of the GTHA that are under-served by public transit, leaving no alternative but to drive.

Existing research suggests that if the road pricing strategy is the result of significant background research, it can be successful at achieving the funding and congestion goals of a given region (Ecola & Light, 2009; Levinson, 2010; Small, 1992). If the City of Toronto and the GTHA wish to become leaders in the introduction of road pricing in Canada, policy-makers must be sure to provide viable alternatives for impacted populations. These options may include, but are not limited to: public transit improvements, a lump-sum refund to impacted residents, and the provision of HOT lanes by re-purposing existing infrastructure. Additionally, recent technological advances make it possible to better account for both the economic and social costs of increasing congestion in urban areas. As with other larger urban regions, managing congestion equitably in the ever-changing GTHA is a complex task. With additional research, and a potential pilot model, road pricing on the Gardiner, DVP and other highways in the region should be seen as a tool policy-makers can use to fund infrastructure and mange congestion fairly and effectively.

6.1 Limitations and future research

The methodology used in this study could be applied to other regions that are considering road pricing strategies to both manage congestion and raise funds for infrastructure spending. The model is limited because it does not factor in existing congestion impacts, or subjective decisions that may be made by commuters in real-life situations. If the data from this study was used to estimate time lost to different income groups and in different parts of the GTHA, it could also provide an understanding of the travel-time impacts that is crucial to evaluating the equity of the road pricing strategy. This analysis could also include the impacts of rerouting cars off the highways and onto local streets. These impacts could come in the form of increased traffic, pollution, and safety concerns for residents, which should be seen as negative externalities to the road pricing strategy. The model also only includes workers, which means it leaves out important trips made for other purposes and by commercial vehicles. These other types of trips will also be significantly impacted by the policy and should be considered in future studies and toll revenue predictions. Finally, this work has not endeavoured to comment on the financial significance of a

$2 or $3 flat toll (or any other pricing structure) on these different income groups, but this would be an important area of analysis for future work.

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