# INCORPORATE TRAVEL MODE CHOICES IN THE REGIONAL STRATEGIC PLANNING MODEL (RSPM) TOOL

## Final Report

### PROJECT 788

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by

Liming Wang
Portland state University
Toulan School of Urban Studies and Planning

for

Oregon Department of Transportation
Research Section
555 13th Street NE, Suite 1
Salem OR 97301

and

Federal Highway Administration
1200 New Jersey Avenue SE
Washington, DC  20590

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16. Abstract

The GreenSTEP family of tools including the Regional Strategic Planning Model (RSPM), has been used in performance-based planning at the state and region level in Oregon and elsewhere. While the current implementation has a sufficient model of household vehicle miles traveled (VMT), it lacks in the representation of non-auto modes, and especially how their usage would respond to various policy inputs. This project develops and implements a multi-modal travel demand module, VETravelDemandMM, for RSPM with the new VisionEval framework. In the development of this new module, we follow the best practices for model development recommended in the literature. In particular, we address the uncertainty and validity in our models by going through rigorous cross-validation and model selection (in addition to variable selection). We use a unique high-resolution nationwide dataset that combines 2009 National Household Travel Survey, EPA's Smart Location Database, and regional roadway and transit services information. This report presents a review of relevant literature and data sources, the results of model estimation, validation, model selection, and sensitivity and prediction tests for the Annual Average Daily VMT model, Personal Miles Traveled models and Trip Frequency and Length models for three non-auto modes.

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# SI* (MODERN METRIC) CONVERSION FACTORS

| APPROXIMATE CONVERSIONS TO SI UNITS | | | | | APPROXIMATE CONVERSIONS FROM SI UNITS | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Symbol | When You Know | Multiply By | To Find | Symbol | Symbol | When You Know | Multiply By | To Find | Symbol |
| | | **LENGTH** | | | | | **LENGTH** | | |
| in | inches | 25.4 | millimeters | mm | mm | millimeters | 0.039 | inches | in |
| ft | feet | 0.305 | meters | m | m | meters | 3.28 | feet | ft |
| yd | yards | 0.914 | meters | m | m | meters | 1.09 | yards | yd |
| mi | miles | 1.61 | kilometers | km | km | kilometers | 0.621 | miles | mi |
| | | **AREA** | | | | | **AREA** | | |
| $in^2$ | square inches | 645.2 | millimeters squared | $mm^2$ | $mm^2$ | millimeters squared | 0.0016 | square inches | $in^2$ |
| $ft^2$ | square feet | 0.093 | meters squared | $m^2$ | $m^2$ | meters squared | 10.764 | square feet | $ft^2$ |
| $yd^2$ | square yards | 0.836 | meters squared | $m^2$ | $m^2$ | meters squared | 1.196 | square yards | $yd^2$ |
| ac | acres | 0.405 | hectares | ha | ha | hectares | 2.47 | acres | ac |
| $mi^2$ | square miles | 2.59 | kilometers squared | $km^2$ | $km^2$ | kilometers squared | 0.386 | square miles | $mi^2$ |
| | | **VOLUME** | | | | | **VOLUME** | | |
| fl oz | fluid ounces | 29.57 | milliliters | ml | ml | milliliters | 0.034 | fluid ounces | fl oz |
| gal | gallons | 3.785 | liters | L | L | liters | 0.264 | gallons | gal |
| $ft^3$ | cubic feet | 0.028 | meters cubed | $m^3$ | $m^3$ | meters cubed | 35.315 | cubic feet | $ft^3$ |
| $yd^3$ | cubic yards | 0.765 | meters cubed | $m^3$ | $m^3$ | meters cubed | 1.308 | cubic yards | $yd^3$ |
| *NOTE: Volumes greater than 1000 L shall be shown in $m^3$. | | | | | | | | | |
| | | **MASS** | | | | | **MASS** | | |
| oz | ounces | 28.35 | grams | g | g | grams | 0.035 | ounces | oz |
| lb | pounds | 0.454 | kilograms | kg | kg | kilograms | 2.205 | pounds | lb |
| T | short tons (2000 lb) | 0.907 | megagrams | Mg | Mg | megagrams | 1.102 | short tons (2000 lb) | T |
| | | **TEMPERATURE (exact)** | | | | | **TEMPERATURE (exact)** | | |
| °F | Fahrenheit | (F-32)/1.8 | Celsius | °C | °C | Celsius | 1.8C+32 | Fahrenheit | °F |

*SI is the symbol for the International System of Measurement

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# DISCLAIMER

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# EXECUTIVE SUMMARY

Performance-based planning helps planners to understand the potential impacts of policy decisions, supporting cost-effective investments and policy choices.  In addition, it can enable monitoring of progress and facilitate needed adjustments, help facilitate communication with the public, and assist with meeting federal regulations and the intent of MAP21.  ODOT has successfully developed a process for and applied performance-based planning in statewide and regional scenario planning efforts. These efforts have led to significant interest by regions and locals to integrate the process and tool ODOT developed into other planning and decision-making efforts. Additionally, ODOT planning is using the tool to help quantify modal and topic plan visions and policies and better communicate the anticipated benefits in ways resonating well with stakeholders and elected officials. As popularity for using the tool and process grow, there is recognition that a deeper understanding is needed to determine how mode choices and mode share may be impacted by policy and investment decisions. This is particularly important when starting to apply the tool in a broader base of planning and decision-making processes to truly understand what may be the best decisions for the entire transportation system (multimodal and intermodal).

This project aims to understand how traveler's mode choices may change in response to different policy and investment decisions. Existing tools like GreenSTEP have a sufficient model of how household vehicle miles traveled (VMT) is likely to change in response to policies like pricing, but they do not currently have the ability to estimate what effect that might have on travel by other modes, and how household mobility/accessibility might be affected. This research places ODOTs performance-based planning process in a multimodal context and enables ODOT, regions, and locals to cost-effectively deliver a transportation system that best achieves respective goals.

This research assesses the impact of different policy decisions on long-term VMT and the use of alternative (non-auto) modes. Additionally, the findings from travel behavior models have been implemented into the proven RSPM model, which supports ODOT and metropolitan area planning.  The use of the tool can help assess the performance of policies in a future world, where key attributes of that future differ significantly from today (pricing, travel options, demographics, etc.), and support strategic investments and policy decisions that simultaneously improve the system and realize community goals. Other ODOT models may also be upgraded in future efforts based on insights from this research and results will be used in general planning decision-making. This capability will provide the information needed for a much more robust performance-based planning tool and to help achieve long-term goals for Oregon, ODOT, and individual regions, counties, and cities.

This project researches the key drivers of multi-modal analysis, as they relate to individual households travel behavior, in particular from built-environment, socio-demographic characteristics, and transportation supply. The research utilizes a unique high resolution nationwide dataset that combines 2009 National Household Travel Survey, EPA's Smart

Location Database, and regional roadway and transit services information to model multi-modal travel behavior at individual household level. With a rigorous model selection process, the selected models balance theoretical foundation, performance, and prediction accuracy. The final models estimated using the unique data sources have been implemented as an open-source module, VETravelDemandMM, for the Regional Strategic Planning Model (RSPM) with the new VisionEval framework. The implementation has been tested for reasonableness of sensitivity and prediction accuracy against the comparable model in GreenSTEP and observed data from Oregon Household Activity Survey. The models and their implementation are producing reasonable results in those tests.

# 1.0 REVIEW OF LITERATURE AND DATA SOURCES

The purpose of this chapter is to review key drivers of mode choice behavior at household and individual level and to develop a mode choice module that incorporates some of most relevant factors. In the literature, those factors largely follow into four categories, namely, socio-demographic characteristics, built environment variables, trip context attributes, and measures of transportation supply and services. Table 1.1 summarizes the factors found in the literature reviewed.

## 1.1 KEY DRIVERS

### 1.1.1 Socio-demographics

There are a number of socio-demographic characteristics influencing an individual's choice of mode of transportation. According to Plaut (2005), there is a difference in preference or behavior in choosing non-motorized commute modes between renters and house owners, with a higher probability of renters switching from motorized to non-motorized. Income is a key variable in travel mode choice: Individuals and households with low income tend to have a high probability of walking and bicycling (Cervero and Duncan 2003; Plaut 2005). Research also suggests that minority population are more likely to walk, with African Americans showing a higher probability of walking (Cervero 1996; Cervero and Duncan 2003). The presence of one or more children is associated with reduced likelihood of using non-auto mode choice (Cervero and Kockelman 1997; Hamre and Buehler 2014), which may be because households with children may have more rigid time budgets related to childcare and school schedules that lead to more complex trip-chaining as well as other factors. Gender plays an important role in the choice of non-motorized modes, with men more likely to use non-motorized travel modes compared to women (Cervero and Kockelman 1997; Hamre and Buehler 2014; Plaut 2005; Schwanen and Mokhtarian 2005). Persons younger than 35 years are more likely to participate in active transportation compared to older age groups (Cervero and Kockelman 1997; Cervero and Duncan 2003; Hamre and Buehler 2014; Plaut 2005; Schwanen and Mokhtarian 2005), and the likelihood of using non-motorized transportation decreases with increasing age (Whitfield, Paul, and Wendel 2015). Access to car reduces the probability of an individual choosing a non-auto mode and increases that of driving (Cervero and Kockelman 1997; Hamre and Buehler 2014; Schwanen and Mokhtarian 2005).

### 1.1.2 Built Environment Variables

Cervero and Kockelman (1997) summarize the built environment factors influencing travel behavior as 3Ds: density, design, and diversity. Later research gradually expands the factors into 5Ds: density, design, diversity, destination accessibility, and distance to transit (Ewing and Cervero 2001; Ewing and Cervero 2010).

Population density has an influence on an individual's mode choice behavior: People who live in high-density areas are more likely to choose non-motorized modes than people who live in low-density areas. The design of built environments in a neighborhood has an influence on whether an individual chooses non-auto modes. The type of intersection influences on whether individuals choose to use auto or non-auto mode of transportation: neighborhoods with a high share of four-way intersections and limited on-street parking tend to average less single-occupancy-vehicle travel for non-work trips (Cervero and Kockelman 1997; Cervero and Duncan 2003; Schwanen and Mokhtarian 2005). Research by Cervero and Duncan (2003) reveals that areas with large city blocks and neighborhoods with large shares of 3-way intersections are not pedestrian/bicycle friendly environments. On the other hand, areas with 4-way intersections as well as intersections with 5 or more converging streets are shown to be pedestrian/bicycle friendly. Neighborhoods with grid pattern streets and few barriers between origin and destination pairs encourage commuting through walking and cycling.

Mixed-use land-uses encourages non-auto commuting, having retail activities and consumer services within 300 feet of one's residence have been found to encourage commuting by non-auto modes (Cervero 1996; Cervero and Kockelman 1997). Automobile usage is lower in higher density, more mixed-use and pedestrian-friendly neighborhoods with a higher share of public transit and slow modes of transportation. The presence of mixed uses of land improves street connectivity, and higher densities appear to support non-motorized modes of travel.

Research by Schwanen and Mokhtarian (2005) compares how commuting mode choice differs by a residential neighborhood and by neighborhood type dissonance (a mismatch between a commuter's current neighborhood and her preferences regarding physical attributes of the residential neighborhood). The level of residential type mismatch increases the probability of commuting by automobile. They found that mismatched urban residents were more likely to use automobile than mismatched suburban residents due to limited transit service. Mode choice differs according to a commuter's residential neighborhood. Residential self-selection process has been found to play a significant role in explaining travel pattern behavior of individuals. Residents in the suburb have a higher probability of automobile use, while residents in urban areas show a higher probability of non-auto modes.

### 1.1.3 Trip Context Variables

Trip context variables – variables directly related to the attributes of a trip, such as trip purpose, trip distance, time of the trip, safety and security, influence traveler's mode choice decision. Trip purposes that do not require punctuality, such as travel to social and recreation/entertainment activities, have a higher probability of choosing walking. For different trip purposes, built environment factors have different influences on an individual's mode choice decision. Distance is an important factor in mode choice behavior. An increase in travel distance means an increase in travel time and effort needed for traveling, which leads to a reduction in commuters using non-auto modes (walking and cycling). The resistance to travel probably may increase disproportionately with distance due to the physical effort required (Heinen, Wee, and Maat 2010). Depending on the distance that a commuter has to travel, he/she will probably have to combine two different modes of travel or make transfers for non-driving modes. The extra effort required to make transfers has been considered to be a significant contributor to transit users' inconvenience. Besides distance, other barriers to walking and cycling include steep slopes, nightfall and less secure environments (Heinen, Wee, and Maat 2010). Singleton and Wang (2014) document the effects of time of travel and safety and security concerns on the decision between driving and non-driving modes, especially for non-motorized modes.

### 1.1.4 Transportation Supply and Services

The provision and level of service of a transportation mode have large impacts on the decision of choosing the mode. There is some overlap between built environment variables, trip context variables and variables measuring transportation supply and services, for example, distance to transit stops (a built environment variable) and transit services (a transportation supply and services variable). But in general, the former describes the built environment of the origin and/or destination or their relation to the transportation supply or services (e.g., distance to transit stops in this case), while the latter measures the presence and quality of transportation supply and services at the origin and destination and/or those connecting the two (e.g., the travel time by transit, the frequency or headway of transit system connecting origin and destination).

Research has found that availability and prices of parking (if not free) at the destination are influential factors in choices between driving and non-driving modes (Hamre and Buehler 2014; Hess 2001). Availability of bike parking and other facilities influences commuter's choice of biking (Hamre and Buehler 2014).

**Table 1.1 Summary of Key Drivers in the Literature**

| Variable | References |
|---|---|
| **Social-demographics** | |
| **Age** | Cervero and Kockelman (1997); Cervero and Duncan (2003); Hamre and Buehler (2014); Plaut (2005); Schwanen and Mokhtarian (2005); Whitfield, Paul, and Wendel (2015) |
| **Gender** | Cervero and Kockelman (1997); Plaut (2005); Schwanen and Mokhtarian (2005); Hamre and Buehler (2014); Whitfield, Paul, and Wendel (2015) |
| **Income** | Cervero and Kockelman (1997); Cervero and Duncan (2003); Plaut (2005); Schwanen and Mokhtarian (2005); Hamre and Buehler (2014); Whitfield, Paul, and Wendel (2015) |
| **Race and Ethnicity** | Cervero and Kockelman (1997); Schwanen and Mokhtarian (2005); Hamre and Buehler (2014); Whitfield, Paul, and Wendel (2015) |
| **Household size** | Cervero and Kockelman (1997); Schwanen and Mokhtarian (2005) |
| **Presence of Children** | Cervero and Kockelman (1997); Hamre and Buehler (2014) |
| **Level of Education** | Cervero and Kockelman (1997); Hamre and Buehler (2014) |
| **Possession of driver's license** | Cervero and Kockelman (1997); Schwanen and Mokhtarian (2005) |
| **Vehicle ownership** | Cervero and Kockelman (1997); Hamre and Buehler (2014) |
| **Housing tenure** | Cervero and Kockelman (1997); Plaut (2005) |
| **Built Environment** | |
| **Population and employment density** | Cervero and Kockelman (1997); Hamre and Buehler (2014) |
| **Land use mix (diversity)** | Cervero (1996); Cervero and Kockelman (1997); Gehrke and Clifton (2015) |
| **Design** | Cervero and Kockelman (1997) |
| **Distance to transit stops** | Cervero and Kockelman (1997) |
| **Distance to retail activities** | Cervero (1996); Cervero and Duncan (2003); |
| **Terrain or Slope** | Rodriguez and Joo (2004) |
| **Trip Context** | |
| **Costs of travel** | Cervero (1996); |
| **Trip Purpose** | Cervero and Duncan (2003) |
| **Travel Time** | Cervero (1996); Hess (2001) |
| **Trip distance** | Cervero and Kockelman (1997); Cervero (1996); Hamre and Buehler (2014) |
| **Time of travel** | Singleton and Wang (2014) |
| **Safety and security** | Singleton and Wang (2014) |
| **Transportation Supply** | |
| **Provision of pedestrian, cycling and transit infrastructure** | Cervero and Duncan (2003); Cervero and Kockelman (1997); Hamre and Buehler (2014) |
| **Level of service** | Cervero and Kockelman (1997); Cervero (1996); Hamre and Buehler (2014) |
| **Parking (availability and price)** | Hamre and Buehler (2014); Hess (2001) |

## 1.2 MODEL FORM OF MODE CHOICE MODELS

Table 1.2 summarizes the common structures of mode choice models. Discrete choice models of various specifications (Multinomial Logit Model & Nested Logit Model), binomial model, and log-odds model are the most common model forms of mode choice models in the literature.

**Table 1.2 Model Form of Mode Choice Models**

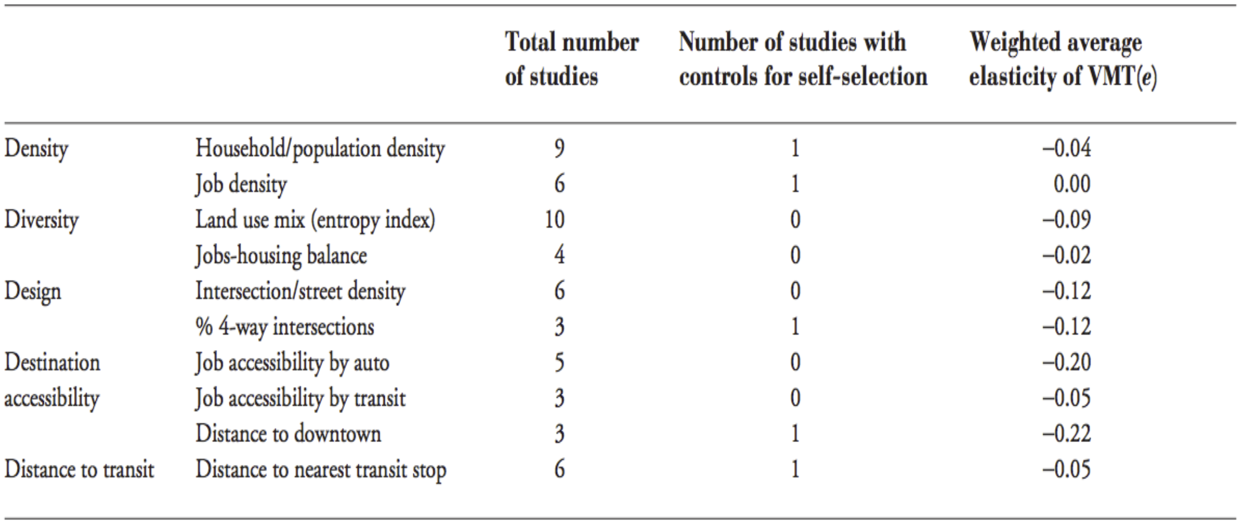
| Model Form | Dependent Variable | References |
|---|---|---|
| **Discrete Choice Model (Multinomial logit)** | Travel modes | Cervero and Duncan (2003); Rodriguez and Joo (2004); Schwanen and Mokhtarian (2005); Singleton and Wang (2014); Srinivasan and Ferreira (2002); Train and McFadden (1978); Ewing, Schroeer, and Greene (2004); Moeckel (2016) |
| **Discrete Choice Model (Nested logit)** | Travel modes with nested structure | Hensher and Ton (2000) |
| **Binomial model (a special case of MNL)** | Choice of one mode versus other modes (e.g. driving alone or not; transit or not) | Cervero (1996); Cervero and Kockelman (1997) |
| **Log-odds** | Probability of choosing mode versus other modes | Hess (2001) |
| **Artificial neural networks (ANN)** | Travel modes | Hensher and Ton (2000) |

Besides travel mode choices, travel by mode aggregated by a person, household, or geography, such as vehicle miles traveled, person mile traveled by modes and number of trips by modes are commonly used as dependent variables in the literature.

## 1.3 ELASTICITIES IN THE LITERATURE

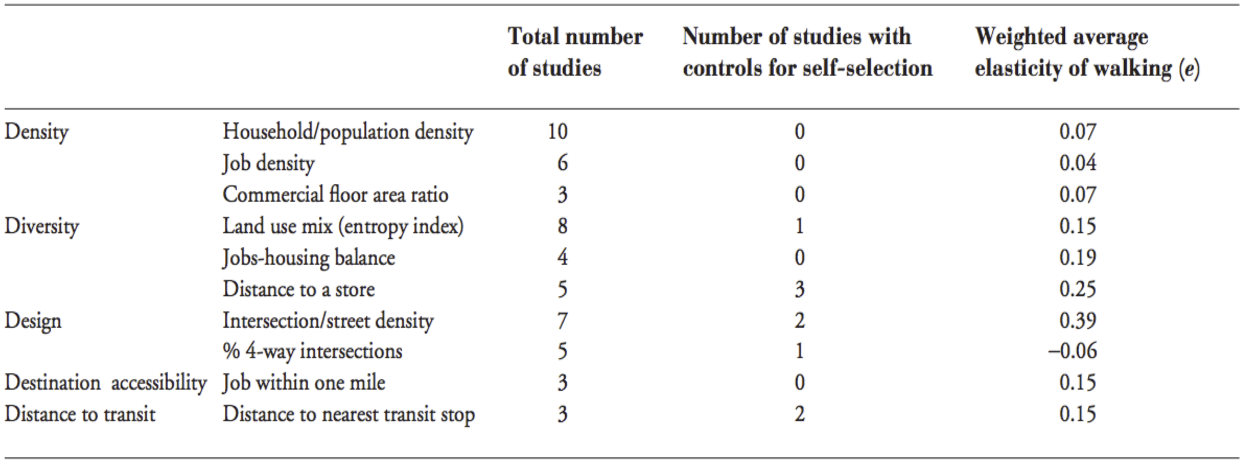
Ewing and Cervero (2001; 2010) conducted two of the most comprehensive review of literature in the relationship between built environment and travel outcomes, including VMT, walk trips, walking/biking person miles traveled. Table 1.3, Table 1.4, and Table 1.5 summarize the weighted average elasticities they calculated in their meta-analysis (Ewing and Cervero 2010).

**Table 1.1 Weighted Average Elasticities of VMT with Respect to Build-Environment Variables**



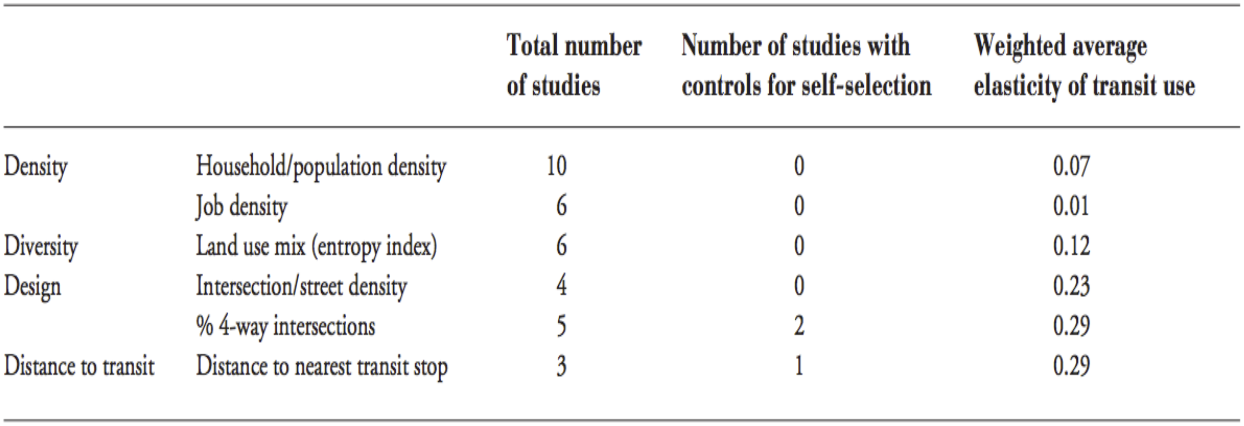
| | | Total number of studies | Number of studies with controls for self-selection | Weighted average elasticity of VMT(*e*) |
|---|---|---|---|---|
| Density | Household/population density | 9 | 1 | –0.04 |
| | Job density | 6 | 1 | 0.00 |
| Diversity | Land use mix (entropy index) | 10 | 0 | –0.09 |
| | Jobs-housing balance | 4 | 0 | –0.02 |
| Design | Intersection/street density | 6 | 0 | –0.12 |
| | % 4-way intersections | 3 | 1 | –0.12 |
| Destination accessibility | Job accessibility by auto | 5 | 0 | –0.20 |
| | Job accessibility by transit | 3 | 0 | –0.05 |
| | Distance to downtown | 3 | 1 | –0.22 |
| Distance to transit | Distance to nearest transit stop | 6 | 1 | –0.05 |

**Table 1.2 Weighted Average Elasticities of Walking with Respect to Build-Environment Variables**



| | | Total number of studies | Number of studies with controls for self-selection | Weighted average elasticity of walking (*e*) |
|---|---|---|---|---|
| Density | Household/population density | 10 | 0 | 0.07 |
| | Job density | 6 | 0 | 0.04 |
| | Commercial floor area ratio | 3 | 0 | 0.07 |
| Diversity | Land use mix (entropy index) | 8 | 1 | 0.15 |
| | Jobs-housing balance | 4 | 0 | 0.19 |
| | Distance to a store | 5 | 3 | 0.25 |
| Design | Intersection/street density | 7 | 2 | 0.39 |
| | % 4-way intersections | 5 | 1 | –0.06 |
| Destination accessibility | Job within one mile | 3 | 0 | 0.15 |
| Distance to transit | Distance to nearest transit stop | 3 | 2 | 0.15 |

**Table 1.3 Weighted Average Elasticities of Transit Use with Respect to Build-Environment Variables**



| | | Total number of studies | Number of studies with controls for self-selection | Weighted average elasticity of transit use |
|---|---|---|---|---|
| Density | Household/population density | 10 | 0 | 0.07 |
| | Job density | 6 | 0 | 0.01 |
| Diversity | Land use mix (entropy index) | 6 | 0 | 0.12 |
| Design | Intersection/street density | 4 | 0 | 0.23 |
| | % 4-way intersections | 5 | 2 | 0.29 |
| Distance to transit | Distance to nearest transit stop | 3 | 1 | 0.29 |

## 1.4 TRAVEL BUDGET

### 1.4.1 Household Travel Time Budget

Trip makers have specific daily travel time budgets, which can be related to their location of residence and modes of travel used during the day (Zahavi 1974). Zahavi in his research examined the stability of travel time budget. Zahavi and Ryan (1980) argued that people spend a fixed percentage of their income on travel. They showed that an average car-owning household spent about 10% to 11 % of their income and carless households spent 3 to 5% of their income on travel. Zahavi (1974) in his study found that time and money budgets allocated to transportation differ within urban regions as a function of age, income and residential location, with location showing to be a better indicator of travel behavior than income. According to Gunn (1981), time spent traveling increases with increase in income. Travel time budget is strongly related to individuals and household characteristics (e.g income level, gender, employment status, and car ownership), attributes of activities at the destination (e.g activity duration), and characteristics of residential areas (e.g density, spatial structure and level of service) (Gunn 1981; Mokhtarian and Chen 2004). Travel time expenditure differs according to area types, with an increase in travel times in areas with higher densities. However, the effects of area characteristics (e.g., density) on travel time expenditure are not as strong as the effects of individual and household characteristics (Gunn 1981; Mokhtarian and Chen 2004). Trip linking affects the number of trips that a traveler makes and therefore, in turn, affects her/his choice of using motorized or non-motorized mode of transport. There is a significant difference in a tripmaker’s travel time budget as it depends on the combination of transport modes used by the traveler.

### 1.4.2 Household Monetary Budget

There is a relationship between the travel money expenditure and area density of a place. The amount of money spent on travel is lower in large urban areas than in small urban areas (Mokhtarian and Chen 2004). According to Golob (1990), if travel decisions are made in a way that is consistent with a household utility-maximizing process subject to constraints associated with time or money budgets, then households will react to changing external conditions in a predictable way. Household travel expenditure is directly related to household income, as a percentage of either income or total expenditure. It is the lowest in the low-income groups and the highest in the middle-income groups (Gunn 1981). Goodwin (1981) also suggests that travel monetary expenditure varies among individuals and groups. However, household expenditure on travel expressed as a proportion of income is almost the same for car-owning households in the same income groups and the same for a wide range of non-car-owning households.

According to Goodwin (1981), when time and money are added together and expressed as a single budget, the resulting generalized cost is relatively stable from different locations and over short periods of time, which would suggest possible trade-offs between travel time expenditure and travel money. Empirical studies have concluded that travel time and money expenditure is unlikely to remain constant over a wide range of circumstances (Goodwin 1981; Mokhtarian and Chen 2004; Tanner 1981).

## 1.5 DATA SOURCES

Since the choice of independent and dependent variables and specifications for mode choice models also depends on what information is available for model estimation and prediction, we explore the datasets available for model estimation, with a special focus on those with nation-wide coverage.

### 1.5.1 National Household Travel Survey (NHTS)

NHTS is a microdata dataset with detailed social-demographic information of households and persons surveyed, and their vehicle and daily (travel day) trip level data (USDOT, Federal Highway Administration 2009). The 2009 NHTS dataset contains data for 150,147 completed households nationwide. The mode choice (dependent variable) and socio-demographic variables, and trip context variables are sufficient for estimating mode choice models. However, the built environment variables and measures of transportation supply and services in the dataset fall short of information needed for a meaningful mode choice model specification. Chapter 2 discusses the built environment variables and measures of transportation supply and services variable included in NHTS. They are either too limited: for example, urban/rural indicators, population density (per squared miles), housing unit density, workers density, and percent of renter-occupied unit variables available at the block group level; or too coarse: for example, another set of density variables at the census tract level and heavy rail status at the MSA level. Most of the built environment and transportation supply and service variables identified in the literature are not available.

Unlike the regional household travel survey data, the geo-coordination or higher resolution geography identifier is not available in the NHTS data, which makes it impossible to join with a built environment database such as the Smart Location Database to get the information missing from the NHTS data.

### 1.5.2 Smart Location Database

The Smart Location Database is a nationwide geographic data resource provided by EPA for measuring location efficiency (Ramsey and Bell, 2014). It includes more than 90 attributes summarizing characteristics such as housing density, diversity of land use, neighborhood design, destination accessibility, transit service, employment, and demographics. See Ramsey and Bell (2014) for a complete list of variables available. Most attributes are available for every census block group in the United States for 2010. Those variables are selected for their impacts to travel behavior, especially the 5D variables identified in the literature (Ewing and Cervero 2001; Ewing and Cervero 2010) as well as transportation supply and services, particularly the transit service. However, the Smart Location Database does not provide information on mode shares. Thus it alone will not be sufficient for estimating mode choice models. Provision of non-motorized transportation infrastructure (for example, bike lanes and cycle tracks) is not available in the Smart Location Database.

### 1.5.3 Place Types

Place types are land use categories that are useful for describing development patterns and their relationship to human behavior (e.g. travel behavior) and well-being (e.g. health) (Gregor, 2016).

In the RSPM mode shift project, we use place types as a means to simplify the work for RSPM users when they create scenarios.

This project adopts the work by Brian Gregor and others and establishes categories over the following 3 dimensions:

- (flag) Location Type: categorizes the general urban context of the place (e.g. a large urbanized area, a small city, etc.).
    1. Urbanized: A contiguous area of urban development which has a large population. Criteria: population within 5 miles >= 30,000 and population within 1 Mile >= 1,000;
    2. Urban near Urbanized: Urban development (e.g. cities, towns, communities) located in the fringe of an urbanized area but are not part of the contiguous urbanized area. Criteria: Population within 15 Miles >= 60,000 and Population within 2 Mile >= 2,000;
    3. Rural Near Urbanized: Urban development not located on the fringe of an urbanized area. Criteria: Population within 15 Miles >= 60,000 and Population within 2 Mile < 2,000
    4. Urban Not Near Urbanized: Urban development not located on the fringe of an urbanized area. Criteria: Population within 15 Miles <= 60,000 and Population within 2 Mile >= 2,000
    5. Rural Not Near Urbanized: Rural development not located on the fringe of an urbanized area. Criteria: Population within 15 Miles <= 60,000 and Population within 2 Mile <= 2,000
- Area Type: categorizes the spatial relationship of urban places to the urban center (e.g. urban center, suburbs, etc.).
    1. Regional Center: Places within urbanized areas that have high levels of population accessibility to jobs and developed at densities and having transportation networks that would allow a substantial portion of the population to get to jobs or other activities by non-auto transport modes. Criteria: if ACCESS is high, and DENSITY is medium or high, and DESIGN is high;
    2. Close In Community: Places within urbanized areas and other urban areas that are located near regional centers or are places with relatively high levels of population accessibility to jobs within urban areas that are not urbanized. Criteria: if ACCESS is high, and DENSITY is medium or high, but DESIGN is not high, or if ACCESS is high and DENSITY is low, or if ACCESS is medium and DENSITY is medium or high;

    3. Suburb/Town: Places in urbanized areas, smaller urban areas, and towns that have lower population accessibility to jobs. Criteria: if ACCESS is high but DENSITY is very low, or if ACCESS is very low or low and DENSITY is not very low;

    4. Low Density/Rural: Low density places with low job accessibility located primarily in rural areas, but may occasionally be found in large vacant tracts in urbanized areas. Criteria: in all other cases.

- Development Type: categorizes the general character of land uses occupying the place (e.g. residential, employment, mixed, etc.)

    1. Low Density/Rural: These are places that have very low-density development in urban or rural areas. In urban areas, these can include large tracts of parkland or greenfields. Criteria: if DENSITY is very low;

    2. Employment: These are places where there are more jobs than households and do not qualify as mixed-use as described below. Criteria: if not Mixed and Diversity1 is greater than 1 (i.e. more jobs than households);

    3. Residential: These are places where there are more households than jobs and do not qualify as mixed-use as described below. Criteria: if not Mixed and Diversity1 is less than 1 (i.e. more households than jobs);

    4. Mixed: These are places where there is a mixture of jobs and households that meet a specified ratio of the two uses. Criteria: if DIVERSITY is high and DENSITY is medium or high and DESIGN is medium or high;

    5. Mixed High: These are places that are mixed and have relatively high densities. Criteria: if Mixed and DENSITY is high and DESIGN is high;

    6. Transit-Oriented Development (TOD): These are places that are mixed, have relatively high densities and have relatively high levels of public transit service. Criteria: if Mixed High and TRANSIT is high, or if Employment and TRANSIT are high and DESIGN is high.

By default, the accessibility measure ACCESS = (2 * EMPTOT_2 * TOTPOP10_5) / 10000 * (EMPTOT_2 + TOTPOP10_5), where EMPTOT_2 is employment within 2-mile radius, and TOTPOP10_5 is total 2010 population within 5-mile radius. The break points for very low, low, medium, and high are 0.1, 0.5 and 2, respectively.

The Density level uses D1D variable in SLD - gross activity density (employment + HUs) on unprotected land (per acre) - with break points of 0.1, 1, and 5.

The Design measure is based on two variables from the SLD: D3amm variable (network density in terms of multimodal links per square mile) and D3apo variable (network density in terms of facility miles of pedestrian-oriented links per square mile). The default break points for D3amm are 1.3, 2.5, and 3.3, while those for D3apo are 12.5, 15.6, and 20. The final value of the Design measure is the maximum value of the two. For example, if the D3amm value is low and D3apo value is medium, the final value of the design measure would be medium.

Diversity Level is a measure of the mixing of jobs and households in the block group. It is based on measures in the SLD: D2A_JPHH (ratio of jobs to households in the block group and the ratio of retail and service jobs to the number of households (E5_RET10 + E5_SVC10)/HH.

Transit Level is a measure of the level of transit service derived from the SLD D4c (aggregate frequency of transit service within 0.25 miles of block group boundary per hour during evening peak period). The threshold values for the 4 levels are 1, 20, and 150.

Based on discussion with the TAC, in particular, Brian and Tara, we primarily use the place types as an intermediate step to facilitate scenario creation, but not as independent variables directly included in the model specification.

### 1.5.4 Additional Datasets

There are two areas where extra data would be beneficial. One area we wish to have a better handle on is the day-to-day variation in mode choice and total demand (for example, the amount of driving measured in vehicle miles traveled) so that we can predict long-term behavior from a daily model. However, NHTS, as well as the three travel surveys above only capture the travel information for one single day. In GreenSTEP, Brian Gregor assumed the stochasticity in household daily VMT model (a linear regression model with transformed VMT as the dependent variable) represents the day-to-day variation in VMT. Such an approximation of weekly VMT from daily information may be imperfect. Verification of the relationship between daily and longer-term VMT and an explicit model of weekly (or annual) VMT may be necessary. A few potential data sets would be helpful in looking into the relationship. In particular, the 2004 – 2006 Traffic Choices Study by the Puget Sound Regional Council. For a pilot project on congestion-based tolling sponsored by Federal Highway Administration, the study placed GPS data loggers into the vehicles of about 275 households in the Seattle metropolitan area. The project recorded roughly 18 months of trip data (from November 2004 to April 2006) and included more than 400 vehicles. Such long-term data would be helpful to look into the relationship between daily and long-term VMT.

Another potential area we are looking into for improvement is the modeling of price elasticities of travel demand. Brian tested three different methods of capturing price elasticities: income effect, price coefficient, and household budget model. There are a number of challenges to get a realistic price elasticities, including

1. The lack of disaggregated panel data that can be used to study how household travel decisions change over time in response to changes in fuel prices;
2. The relatively low historical price of fuel;
3. The prospect for future fuel prices that may be several times greater than present prices;
4. A lack of research consensus on the magnitude of the effects; and,

5. The difficulty of sorting out the short- and long-range effects.

Because of these challenges, the first two methods do not have sufficient sensitivity and Brian adopted the household budget model. All the challenges Brian identified above remain for the current project. Using the household budget model as the baseline model, we hope to draw from literature around the world (for example, Graham and Glaister, 2002) on the magnitude of the price elasticities and explore alternative methods of incorporating the elasticities into the new model of travel demand. Tolling studies such as the Puget Sound Traffic Choices Study provide some useful information on the price elasticities of travel demand (even though not from fuel price change).

These are a few additional datasets the project team reviewed but did not use for this project.

#### *1.5.4.1 Regional Household Travel Surveys*

Like NHTS data, regional household travel data, such as the Oregon Household Activity Survey (OHAS), is a microdata dataset with detailed social-demographic information of households and persons surveyed, and their vehicle and daily (travel day) trip level data. The advantage of regional travel survey data is that the geo-coordination or higher resolution geography identifier may be obtained from the survey agency, and such information can be used to join it with the built environment and transportation supply and service information. However, the process of retrieving and processing each dataset can be very tedious as each survey dataset may be in different format and coding, and it is unknown whether the data available will be representative. For example, models estimated from the OHAS data may not be easily transferable to other states/regions – a goal of the RSMP tool, as Oregon, is likely too unique in many ways. Such an effort may only be worthwhile if data for one or multiple diverse regions can be obtained and processed.

#### *1.5.4.2 Consumer Expenditure Survey*

The Consumer Expenditure Survey (CE) provides a continuous and comprehensive flow of data on the buying habits of American consumers (US Bureau of Labor Statistics 2014). These data are used widely in economic research and analysis, and in support of revisions of the Consumer Price Index. Bureau of Labor Statistics (BLS) provides two public used microdata: an interview survey containing data on monthly expenditures for housing, apparel and services, transportation, healthcare, entertainment, personal care, reading, education, food, tobacco, cash contributions, and personal insurance and pensions, as well as income and characteristics data, and a diary survey with data on weekly expenditures of frequently purchased items such as food at home, food away from home, alcoholic beverages, smoking supplies, personal care products and services, and nonprescription drugs, as well as income and characteristics data. Both surveys include detailed information on social-demographics including household income and housing characteristics that may be useful for estimating mode choice models. The interview survey includes vehicle ownership information, detailed out-of-pocket costs of transportation, such as vehicle operating expenses including vehicle repairing and maintenance, gasoline, and costs for using mass transit for various purposes (work, school, and other places). It also asks the surveyors about long trips (overnight trips or those longer than 75 miles), modes used and related costs.

The advantage of the CE data is that the information therein makes it easy to investigate monetary travel costs of overall household expenses (budget) and/or household income. There may be a possibility to infer mode shares from vehicle ownership, operating expenses, and costs of using mass transit, etc. However, since the CE dataset was not collected for such purpose, non-motorized travel is not reported; trip context, built environment, and transportation supply and service variables are not available.

The CDC Active Transportation Surveillance (Whitfield, Paul, and Wendel 2015) reviews national datasets that can be used for surveillance of active transportation usage in the US. The authors review not only datasets commonly used in travel behavior research such as American Community Survey and NHTS, but also datasets not so commonly used, such as the American Time Use Survey, National Health and Nutrition Examination Survey, and National Health Interview Survey. Not all of them are useful for the purpose of estimating mode choice models, as the health-focused surveys only partial mode information (active transportation mostly).

### 1.5.5 Conclusion

Mode choice behavior is a core element of travel behavior and has significant implications in transportation planning and investment decision. Increasing shares of public transit and non-motorized modes of travel has been promoted as a potential policy lever to reach more sustainable urban development and as a policy goal itself. This project aims to enhance the mode choice module for Regional Strategic Planning Model that links policy inputs to more refined mode choice outcomes. Task 1 reviews the literature, explores available datasets and sets the stage for later tasks. The four categories of variables – socio-demographics, built environment, trip context, and transportation supply, and services – identified in the literature are important to model household or individual level mode choice decision. On the data end, there is a challenge as nationwide data currently available are unable to provide a complete set of variables:

- Socio-demographic variables are influential and abundant in data with nationwide coverage (NHTS);

- Nationwide built environment and transportation supply/service (particularly transit) variables are available (Smart Location Database), but difficult to mesh with travel behavior (mode choices) and socio-demographic variable;

- Regional data can be meshed to get all necessary information but may post a challenge of transferability and requires extra data processing.

The ideal data sources are the NHTS dataset joined with the Smart Location Database. If such dataset cannot be accessed early in the project, an alternative would be a consolidation of regional travel survey data from diverse regions for similar years (ideally circa 2010), which can be then joined with the Smart Location Database or other data sources for built environment information. Consumer Expenditure Survey data would be the third option.

# 2.0 DATA SOURCES AND DESCRIPTIVE ANALYSIS

The primary data sources we identified and used for later tasks are the 2009 National Household Travel Survey (NHTS) and 2010 EPA Smart Location Database (SLD). Additional data sources include Texas Transportation Institute's (TTI) Urban Mobility Report dataset and National Transit Database. We retrieved the 2009 NHTS data with confidential block group level residence location (and Census Tract and ZIP code of workplace location), which is the ideal data set we eyed for modeling mode choice. With the confidential residential block group location, we joined the 2009 NHTS with the 2010 SLD to get a combined dataset of travel information and built environment/urban form variables of households' residential block group.

## 2.1 2009 NHTS

In addition to surveyed households' socio-demographic characteristics, the 2009 NHTS (USDOT, Federal Highway Administration 2009) collected daily trips taken in a 24-hour period and includes:

- purpose of the trip (work, shopping, etc.);
- means of transportation used (car, bus, subway, walk, etc.);
- how long the trip took, i.e., travel time;
- time of day when the trip took place;
- day of the week when the trip took place; and
- if a private vehicle trip:
    - number of people in the vehicle, i.e., vehicle occupancy;
    - driver characteristics (age, sex, worker status, education level, etc.); and
    - vehicle attributes (make, model, model year, the amount of miles driven in a year).

The 2009 NHTS included 150,145 households, 308,901 household members and 1,167,321 trips.

### 2.1.1 Travel Mode Reclassification

According to the codebook for G34 TRPTRANS, we collapse the original NHTS modes into 5 modes in our model development: Auto (Driving), transit, biking, walking, and other modes (not modeled). Table 2.1 shows the crosswalk between these two classifications.

**Table 2.1 Crosswalk between NHTS Modes and RSPM Modes**

| NHTS Mode Code | NHTS Mode Name | RSPM Mode Name |
|---|---|---|
| **1** | Car | Auto |
| **2** | Van | Auto |
| **3** | SUV | Auto |
| **4** | pickup truck | Auto |
| **5** | other truck | Auto |
| **6** | recreational vehicle | Auto |
| **7** | motorcycle | Auto |
| **9** | transit bus | Transit |
| **10** | commuter bus | Transit |
| **11** | school bus | Transit |
| **12** | charter bus | Transit |
| **13** | city to city bus | Transit |
| **14** | Shuttle bus | Transit |
| **15** | Amtrak | Transit |
| **16** | Commuter train | Transit |
| **17** | Subway | Transit |
| **18** | Streetcar/trolley | Transit |
| **22** | Bicycle | Bike |
| **23** | Walk | Walk |
| **8** | Light electric veh (golf cart) | Other |
| **19** | taxi cab | Other |
| **20** | Ferry | Other |
| **21** | airplanes | Other |
| **24** | Special transit-people w/disabilities | Other |

## 2.1.2 Unweighted trip frequencies by mode

**Table 2.2 Unweighted Trip Frequencies by Mode**

| mode | n | % |
|---|---|---|
| **Auto** | 955345 | 88.5 |
| **Walk** | 93182 | 8.63 |
| **Transit** | 22483 | 2.08 |
| **Bike** | 8753 | 0.811 |

### 2.1.3 Shares of trips by trip purpose and mode

Table 2.3 Shares of Trips by Trip Purpose and Mode

| TRIPPURP | mode | n | % |
|---|---|---|---|
| **HBO** | Auto | 195189 | 84.7 |
| **HBO** | Bike | 1023 | 0.444 |
| **HBO** | Transit | 13157 | 5.71 |
| **HBO** | Walk | 21161 | 9.18 |
| **HBSHOP** | Auto | 243832 | 95.2 |
| **HBSHOP** | Bike | 1097 | 0.429 |
| **HBSHOP** | Transit | 1251 | 0.489 |
| **HBSHOP** | Walk | 9814 | 3.83 |
| **HBSOCREC** | Auto | 110582 | 71.5 |
| **HBSOCREC** | Bike | 4832 | 3.12 |
| **HBSOCREC** | Transit | 812 | 0.525 |
| **HBSOCREC** | Walk | 38473 | 24.9 |
| **HBW** | Auto | 102319 | 95.9 |
| **HBW** | Bike | 684 | 0.641 |
| **HBW** | Transit | 1671 | 1.57 |
| **HBW** | Walk | 2009 | 1.88 |
| **NHB** | Auto | 303423 | 91.4 |
| **NHB** | Bike | 1117 | 0.337 |
| **NHB** | Transit | 5592 | 1.69 |
| **NHB** | Walk | 21725 | 6.55 |

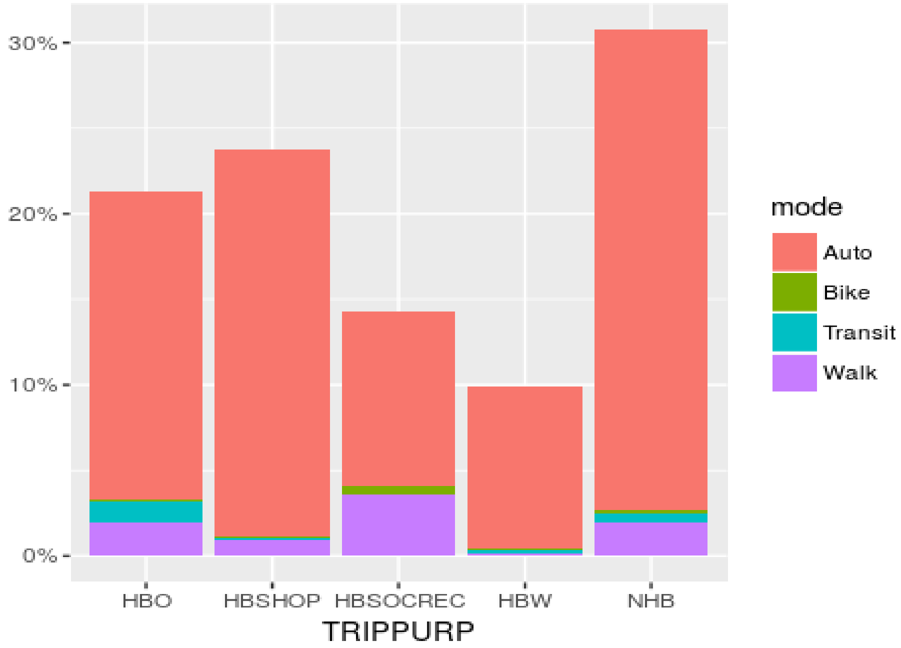


Figure 2.1 Shares of trips by trip purpose and mode

### 2.1.4 Distribution of raw trip distance (miles)

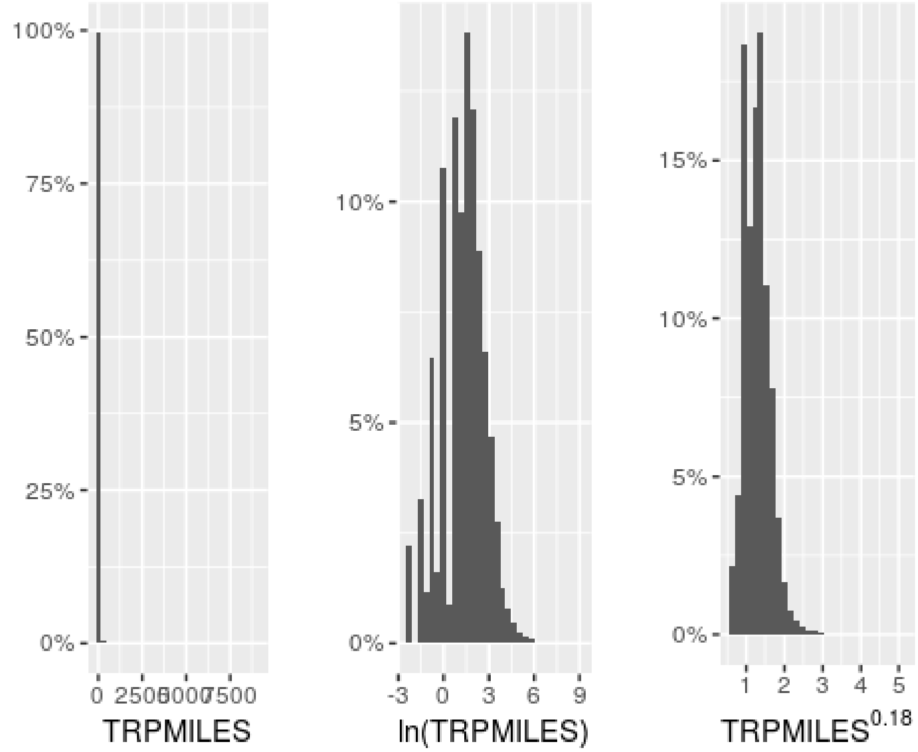


**Figure 2.2 Histograms of raw trip distance (miles)**

### 2.1.5 Trip distance by mode

**Table 2.4 Raw Trip Distance by Mode**

| mode | n | 5% | 25% | 50% | 75% | 95% | 99% | max | mean | sd |
|---|---|---|---|---|---|---|---|---|---|---|
| **Auto** | 964961 | 0.556 | 2 | 4 | 10 | 32 | 91 | 5600 | 9.82 | 26.9 |
| **Bike** | 8842 | 0.111 | 0.556 | 1 | 3 | 10 | 22.6 | 320 | 2.58 | 6.25 |
| **Other** | 9940 | 0.222 | 1 | 4 | 12 | 238 | 1500 | 5000 | 61.3 | 297 |
| **Transit** | 22709 | 0.556 | 2 | 5 | 10 | 30 | 95 | 2005 | 9.85 | 31.3 |
| **Walk** | 93809 | 0.111 | 0.222 | 0.5 | 0.889 | 2 | 4 | 46 | 0.687 | 0.859 |

Since raw trip distance is very skewed (Table 2.4), Table 2.5 show trip distance distribution after trips made by vehicles w/ commercial license plates and with distance above the 99 percentile are filtered. Results below are after applying this filter.

**Table 2.5 Trip Distance by Mode after Filter**

| mode | n | 5% | 25% | 50% | 75% | 95% | 99% | max | mean | sd |
|---|---|---|---|---|---|---|---|---|---|---|
| **Auto** | 955345 | 0.556 | 2 | 4 | 10 | 29 | 57 | 91 | 8.03 | 10.8 |
| **Bike** | 8753 | 0.111 | 0.556 | 1 | 2.89 | 8 | 17 | 22 | 2.21 | 3.11 |
| **Transit** | 22483 | 0.556 | 2 | 4 | 9 | 26 | 55 | 95 | 7.73 | 10.3 |
| **Walk** | 93182 | 0.111 | 0.222 | 0.5 | 0.778 | 2 | 3 | 4 | 0.646 | 0.612 |

### 2.1.6 Total household travel distance (miles) and travel time (minutes) by mode used

**Table 2.6 Total Household Travel Distance (miles) by Mode**

| mode | n | 5% | 25% | 50% | 75% | 95% | 99% | max | mean | sd |
|---|---|---|---|---|---|---|---|---|---|---|
| **Auto** | 127999 | 4 | 17 | 40 | 80 | 183 | 308 | 1205 | 59.9 | 64.9 |
| **Bike** | 3412 | 0.222 | 1.11 | 3 | 7 | 20 | 37.1 | 76 | 5.67 | 7.61 |
| **Transit** | 9107 | 1 | 4 | 10 | 22 | 66 | 130 | 434 | 19.1 | 27.3 |
| **Walk** | 32780 | 0.222 | 0.556 | 1.11 | 2.22 | 5.44 | 8.67 | 40.2 | 1.84 | 1.88 |

**Table 2.7 Total Household Travel Time (minutes) by Mode**

| mode | n | 5% | 25% | 50% | 75% | 95% | 99% | max | mean | sd |
|---|---|---|---|---|---|---|---|---|---|---|
| **Auto** | 127999 | 19 | 50 | 97 | 167 | 325 | 500 | 2084 | 125 | 106 |
| **Bike** | 3412 | 5 | 19 | 30 | 60 | 140 | 240 | 515 | 48.6 | 49.6 |
| **Transit** | 9107 | 13 | 31 | 60 | 106 | 220 | 380 | 1155 | 82.7 | 79.5 |
| **Walk** | 32780 | 4 | 15 | 30 | 55 | 118 | 196 | 1110 | 40.6 | 42.4 |

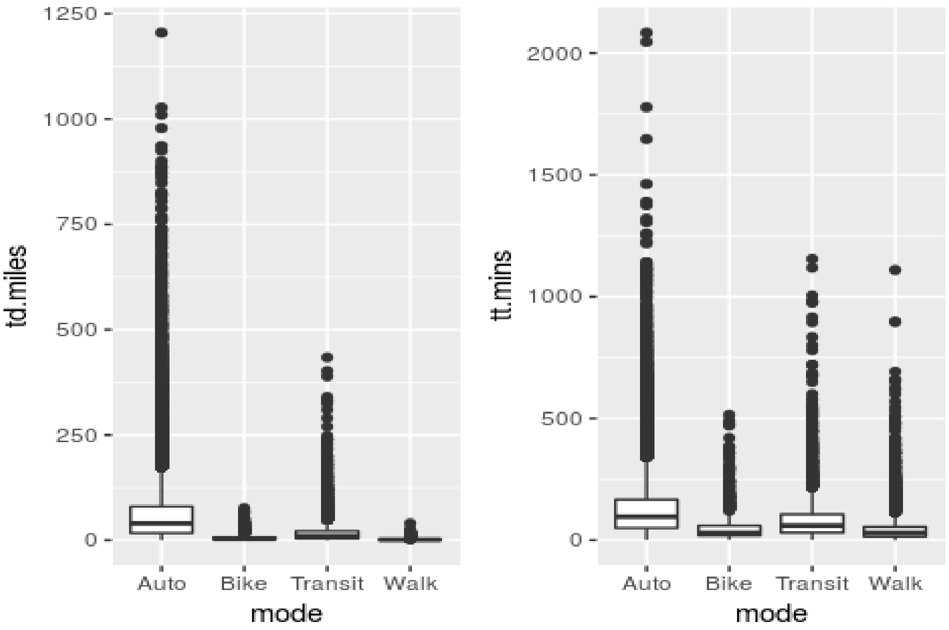


**Figure 2.3 Boxplots of total household travel distance (miles) and travel time (minutes) by mode**

### 2.1.7 Survey day VMT versus annual VMT

There are a few VMT measures available in the 2009 NHTS dataset:

- DVMT: Calculated trip distance (miles) for auto trips;
- ANNMILES: Self-reported annualized miles estimate (containing many missing values);
- BESTMILE: Best estimate of annual miles (by ORNL), from which an annual average daily VMT (AADVMT) is derived (AADVMT=BESTMILE/365).

Figure 2.4 shows the distribution of survey day VMT, annual average daily VMT and their transformed values.

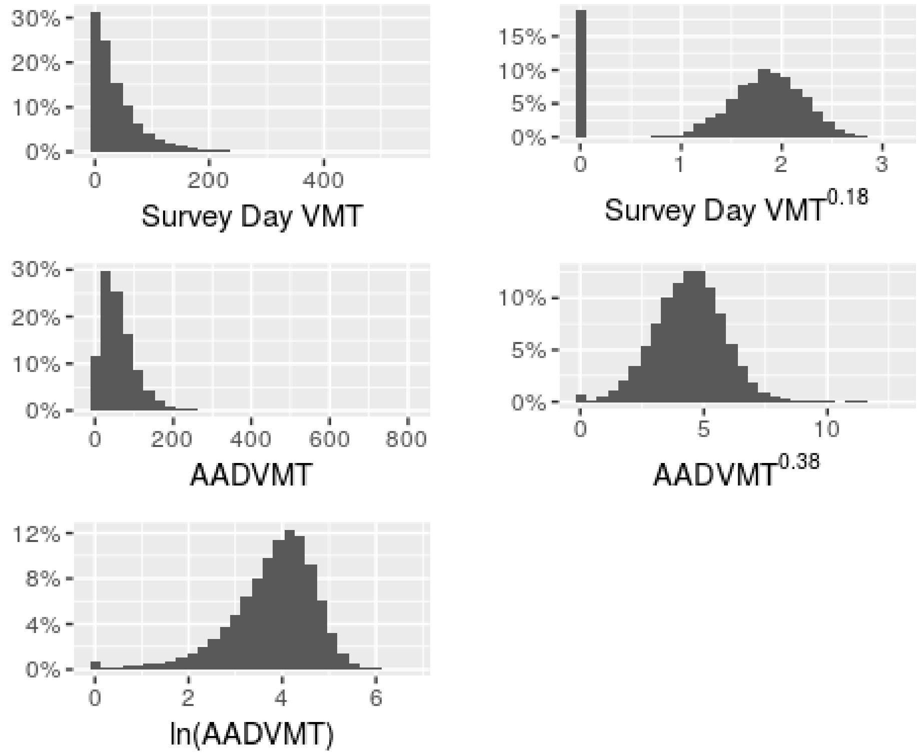


**Figure 2.4 Distribution of survey day VMT, annual average daily VMT, and their transformation**

After consulting with the Technical Advisory Committee, we directly model long-term AADVMT. For strategic planning tools like RSPM, annual average daily VMT (AADVMT) is more useful than modeling VMT on the day of the survey and approximating average or annual VMT, which is commonly done in practice due to data availability or limitation. For example, GreenSTEP and the RSPM currently synthesize AADVMT for each household because the 2001 NHTS estimates of annual VMT are incomplete (available for less than half of the records) with “questionable data quality” (Clifton and Gregor 2012).

## 2.2 SMART LOCATION DATABASE (SLD)

The Smart Location Database (Ramsey and Bell 2014) is a nationwide geographic data resource for measuring location efficiency. It includes more than 90 attributes summarizing characteristics such as housing density, diversity of land use, neighborhood design, destination accessibility, transit service, employment, and demographics. Most attributes are available for every census block group in the United States. The variables in SLD are largely organized according to the 5D built environment measures: Density, Diversity, Design, Transit, Destination, in addition to demographics and employment. A complete list of the variables can be found here.

The confidential NHTS data contain Census Block Group information of households' residence Census block group (2010 geography), which is joined with SLD to retrieve land use features for these locations. Land use information in SLD provides a rich set of factors that are documented in existing research literature to have an influence on households' travel behavior including mode choices and travel distance.

All households in the 2009 NHTS data have a matched block group in the SLD.

## 2.3 DESCRIPTIVE STATISTICS

Table 2.8 presents a select subset of variables with descriptions, sources, and summary statistics after data joining and cleaning up.

**Table 2.8 Variables, their Source, Description and Summary Statistics**

| Name | Source | Description | Mean | std dev |
|---|---|---|---|---|
| **AADVMT** | NHTS | Household Annual average daily VMT | 59.33 | 48.58 |
| **DVMT** | NHTS | Household VMT on the survey day | 40.12 | 45.58 |
| **TransitTrips** | NHTS | Transit trips during the day of the survey | 0.173 | 0.7727 |
| **BikeTrips** | NHTS | Biking trips during the day of the survey | 0.06922 | 0.5103 |
| **WalkTrips** | NHTS | Walking trips during the day of the survey | 0.7422 | 1.667 |
| **TransitPMT** | NHTS | Transit Personal Mile Traveled during the day of the survey | 1.37 | 9.474 |
| **BikePMT** | NHTS | Biking Personal Mile Traveled during the day of the survey | 0.1597 | 1.649 |
| **WalkPMT** | NHTS | Walking Personal Mile Traveled during the day of the survey | 0.4816 | 1.282 |
| **Age0to14** | NHTS | Number of household members younger than 14 | 0.2015 | 0.5745 |
| **Age65Plus** | NHTS | Number of household members older than 65 | 0.6203 | 0.773 |
| **CENSUS_R** | NHTS | Census division classification for home address: New England, Middle Atlantic, East North Central, West North Central, South Atlantic, East South Central, West South Central, Mountain, or Pacific | | |
| **DrvAgePop** | NHTS | Driving age population | 2.034 | 0.918 |
| **Drivers** | NHTS | Number of drivers in the household | 1.741 | 0.7641 |
| **HhSize** | NHTS | Count of household members | 2.235 | 1.192 |
| **LifeCycle** | NHTS | Household life cycle classification: Single, Couple w/o children, Couple w/ children, or Empty Nester | | |
| **LogIncome** | NHTS | log total household income | 10.72 | 0.8629 |
| **Vehicles** | NHTS | Number of vehicles | 2.003 | 1.151 |
| **VehPerDriver** | NHTS | Number of vehicles per licensed driver | 1.126 | 0.5832 |
| **Workers** | NHTS | Number of workers in household | 0.952 | 0.9144 |
| **D1B** | SLD | Gross population density (people/acre) on unprotected land | 5.999 | 15.77 |
| **D2A_EPHHM** | SLD | Employment and household entropy | 0.471 | 0.2256 |
| **D2A_WRKEMP** | SLD | Household Workers per Job, as compared to the region | 9.872 | 31.01 |
| **D3bpo4** | SLD | Intersection density in terms of pedestrian-oriented intersections having four or more legs per square kilometer | 12.95 | 22.77 |
| **D4c** | SLD | Aggregate frequency of transit service within 400 meters of block group boundary per hour during evening peak period | 25.42 | 65.36 |
| **D5** | Place Types | Accessibility measure ACCESS = (2 * EMPTOT_2 * TOTPOP10_5) / 10000 * (EMPTOT_2 + TOTPOP10_5), where EMPTOT_2 is employment within 2-mile radius, and TOTPOP10_5 is total 2010 population within 5-mile radius | 0.9763 | 3.652 |
| **FwyLaneMiPC** | HPMS | Urbanized area freeway lane-kilometers per 1,000 person | 0.0007008 | 0.0003855 |
| **TranRevMiPC** | NTD | Urbanized area transit annual vehicle revenue kilometers per 1,000 person | 0.01703 | 0.01184 |

# 3.0 MODEL DESIGN AND ESTIMATION

## 3.1 INTRODUCTION

Task 2 of the project is to "select one or more possible model designs for RSPM mode shift, estimate model parameters and evaluate the designs and estimated parameters with sensitivity tests and validation". More specifically, the plan is to select and estimate one or more possible designs of the mode choice model based on literature review and data exploration in Task 1 and to understand what mode shifts occur as vehicle travel is reduced, incorporating and testing interactions in RSPM. These approaches build on the existing RSPM module and utilize household and land use inputs and budget constraints already embedded in the RSPM tool. The PSU team will suggest functional form and independent variables for model estimation with associated data sources for estimation and validation. PSU researchers will also identify sensitivity tests to assess the upgraded model with literature elasticities, repeating some of the tests previously calculated by the RSPM to ensure these remain intact, as well as adding tests to evaluate the new functionality. The PSU team will discuss and coordinate with Brian Gregor in the model design and estimation process, as he implements the RSPM common framework, to make sure the design and data format matches the latest RSPM modeling framework. ODOT staff shall review and adjust the proposed designs, estimation data, and validation data/approach.

This chapter is adapted from the deliverable of Task 2, a working paper that describes model designs, estimation, results of sensitivity tests and validation; the documented R scripts used to process and analyze data is available on the project GitHub page: https://github.com/cities/RSPM_ModeChoice.

For auto mode, Annual Average Daily VMT (AADVMT) is used, instead of the more common Daily VMT (on the day of the survey), is modeled at the household-level. After testing a handful of different model structures, a power-transformed (i.e., Box-Cox transformation) linear regression model is selected for its simplicity, performance, and prediction accuracy.

Three specifications were considered for estimating the non-auto modes miles by transit, walk & bike in metro and non-metro areas. Of the 3 models, the first two result in person level non-auto miles rolled up to the household level. The last is a household level model

- **Person Miles Traveled (PMT)** – hurdle model of PMT for the three non-driving modes: transit, bike, and walk. Since there is a predominant number of zeros in non-driving PMT, hurdle model is used to model them as it captures both the zero and non-zero data generation processes in a single model structure.

- **Trip Frequency-Length (TFL)** – hurdle models (one for each mode) of trip Frequency of transit, bike, and walk trips, and, when the trip frequency is not zero, a power-transformed linear regression models of average trip length by mode.

- **Total Person Miles Traveled by Mode (TPMTM)** – A linear regression model (log or power transformed) of total household person mile traveled, and a log-odds exponential model of total miles allocated to modes (including driving).

## 3.2 CURRENT GREENSTEP DVMT MODELS

GreenSTEP models Daily Vehicle Mile Travel (VMT) by drivers in its household travel model and does not explicitly model non-driving travel (for example, by transit or non-motorized modes), except for diversion of short-distance trips to bike. The current household travel model in GreenSTEP has two sequential (conditional) models: a binary model of whether a household will have non-zero daily VMT (Zero DVMT model) and a regression model of the actual daily VMT for households with non-zero VMT (DVMT model). Such a model structure provides a good balance between behavioral realism as well as simplicity and performance.

### 3.2.1 Zero DVMT model

$$\boldsymbol{P(DailyVMT == 0) = logit(DrvAgePop + LogIncome + Htppopdn + Age65Plus + Hhvehcnt + ZeroVeh + Tranmilescap + Urban{:}Tranmilescap)} \tag{3-1}$$

The estimated model coefficients are listed in Table 3.1.

**Table 3.1 Binomial Logit Models of Zero DVMT**

| | metro | non-metro |
|---|---|---|
| **(Intercept)** | 4.71 (0.14)*** | 4.65 (0.15)*** |
| **DrvAgePop** | -0.20 (0.01)*** | -0.27 (0.02)*** |
| **LogIncome** | -0.55 (0.01)*** | -0.52 (0.01)*** |
| **HTPPOPDN** | 0.00 (0.00)*** | -0.00 (0.00) |
| **Age65Plus** | 0.11 (0.01)*** | 0.15 (0.02)*** |
| **HHVEHCNT** | -0.30 (0.02)*** | -0.22 (0.01)*** |
| **ZeroVeh** | 3.49 (0.08)*** | 3.17 (0.10)*** |
| **Tranmilescap** | 6.96 (1.03)*** | |
| **AIC** | 56420.05 | 44534.53 |
| **BIC** | 56494.31 | 44597.37 |
| **Log Likelihood** | -28202.03 | -22260.26 |
| **Deviance** | 56404.05 | 44520.53 |
| **Num. obs.** | 79379 | 58557 |

$^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$

### 3.2.2 DVMT model

$$lm((DailyVMT)^{0.18} = Census\_r + LogIncome + Htppopdn + Hhvehcnt + ZeroVeh + Tranmilescap + Fwylnmicap + DrvAgePop + Age65Plus + Urban + Htppopdn{:}Tranmilescap). \tag{3-2}$$

The estimated model coefficients are listed in Table 3.2.

**Table 3.2 Power-Transformed Regression Models of DVMT (DVMT > 0)**

| | metro | non-metro |
|---|---|---|
| **(Intercept)** | 4.71 (0.14)*** | 4.65 (0.15)*** |
| **DrvAgePop** | -0.20 (0.01)*** | -0.27 (0.02)*** |
| **LogIncome** | -0.55 (0.01)*** | -0.52 (0.01)*** |
| **HTPPOPDN** | 0.00 (0.00)*** | -0.00 (0.00) |
| **Age65Plus** | 0.11 (0.01)*** | 0.15 (0.02)*** |
| **HHVEHCNT** | -0.30 (0.02)*** | -0.22 (0.01)*** |
| **ZeroVeh** | 3.49 (0.08)*** | 3.17 (0.10)*** |
| **Tranmilescap** | 6.96 (1.03)*** | |
| **AIC** | 56420.05 | 44534.53 |
| **BIC** | 56494.31 | 44597.37 |
| **Log Likelihood** | -28202.03 | -22260.26 |
| **Deviance** | 56404.05 | 44520.53 |
| **Num. obs.** | 79379 | 58557 |

$^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$

### 3.2.3 Combined model

We can combine both model steps and assess the accuracy of its predictions with in-sample validation. The validation results measured by RMSE and normalized RMSE are in Table 3.3 .

**Table 3.3 Accuracy of Combined GreenStep DVMT Models**

| | rmse | nrmse | r2 |
|---|---|---|---|
| **metro** | 51.8 | 1.57 | 0.11 |
| **non_metro** | 64.9 | 1.54 | 0.102 |

Another related model in GreenSTEP is the household budget model that captures the price elasticity of travel. The budget approach to modeling is based on the perspective that households make their travel decisions within money and time budget constraints. According to Brian's research on historical consumer expenditure survey data, household spending on gasoline and other variable costs are done within a household transportation budget that is relatively stable, as households shift expenses between transportation budget categories when gasoline prices fluctuate. Households will necessarily reduce their travel in direct proportion to the cost increase only when fuel prices or other variable costs increase to the point where it is no longer possible to shift money from other parts of the transportation budget (B. Gregor 2010). Brian assumes the transition between inelastic and elastic behavior will not be abrupt unless there is little time for the household to recognize the impact of the cost increases on the budget or respond to the cost increases. If the changes are more gradual, the transition will be less abrupt. Given the focus of GreenSTEP/RSPM on long-term forecasting, we would only need to model long-run elasticities.

## 3.3 PROPOSED NEW MODELS

### 3.3.1 AADVMT Model (Power-transformed linear regression model)

Instead of modeling DVMT and then approximating annual VMT from it, an alternative is to directly model annual average daily VMT (AADVMT). Both 2001 and 2009 NHTS contain annual mile estimates for each vehicle in a household provided by ORNL, from which we can derive AADVMT.

$$\mathbf{AADVMT}_{\boldsymbol{h}} = \frac{\sum_{\boldsymbol{v_h}=\mathbf{0}}^{\boldsymbol{V_h}} \mathbf{AVMT}_{\boldsymbol{v_h}}}{\mathbf{365}}$$

**(3-3)**

Where

- $\mathrm{AADVMT}_h$ is the annual average daily VMT for household $h$,
- $v_h \in \{0, \dots, V_h\}$ indexes vehicles in household $h$,
- $V_h$ is number of vehicles in the household $h$, and
- $\mathrm{AVMT}_{v_h}$ is the annual VMT driven for vehicle $v_h$.

In model estimation, household AADVMT $\mathrm{AADVMT}_h$ computed with Equation (3-3) is then regressed on independent variables including household characteristics, built environment, and transportation supply:

$$\mathbf{AADVMT}_{\boldsymbol{h}} = \boldsymbol{f}(\mathbf{SD}_{\boldsymbol{h}}, \mathbf{BE}_{\boldsymbol{h}}, \mathbf{TS}_{\boldsymbol{R_h}})$$

**(3-4)**

Where

- $\mathrm{AADVMT}_h$ is the annual average daily VMT for household $h$,
- $\mathrm{SD}_h$ represents the demographic and social-demographic characteristics of household $h$,
- $\mathrm{BE}_h$ is the built environment variables (of various geographical resolution) of household $h$, and

- $\text{TS}_{R_h}$ is the transportation supply of the region where household $h$ resides.

In terms of model structure options for household AADVMT model ($f(.)$ in Equation (3-4)), we consider three of the most commonly used structures in the literature (Ewing and Cervero 2001): linear and transformed linear regression models, and a hurdle model, as well as the model structure used in the current version of the travel demand module of RSPM: 2-step models of binomial logit and linear/non-linear regression model.

After comparing all three model structures for predictive accuracy in cross-validation, the power-transformed (with $\lambda$=0.38) linear regression model is chosen.

Table 3.4 shows the estimated coefficients of the AADVMT model with the power-transformed (with $\lambda$=0.38) linear regression model structure, while Table 3.5 shows its prediction accuracy measured by RMSE (Root Mean Squared Error) and normalized RMSE.

**Table 3.4 Power-Transformed AADVMT Model**

| | **non_metro** | **metro** |
|---|---|---|
| **(Intercept)** | -1.27 (0.06)*** | -0.69 (0.07)*** |
| **Drivers** | 0.65 (0.01)*** | 0.69 (0.01)*** |
| **HhSize** | 0.06 (0.01)*** | |
| **Workers** | 0.12 (0.01)*** | 0.19 (0.01)*** |
| **CENSUS_RNE** | -0.10 (0.01)*** | -0.10 (0.01)*** |
| **CENSUS_RS** | 0.06 (0.01)*** | 0.07 (0.01)*** |
| **CENSUS_RW** | -0.23 (0.01)*** | -0.11 (0.01)*** |
| **LogIncome** | 0.31 (0.01)*** | 0.20 (0.01)*** |
| **Age0to14** | 0.04 (0.01)*** | 0.11 (0.01)*** |
| **Age65Plus** | -0.10 (0.01)*** | -0.08 (0.01)*** |
| **log1p(VehPerDriver)** | 1.71 (0.02)*** | 1.91 (0.03)*** |
| **LifeCycleEmpty Nester** | -0.26 (0.02)*** | -0.31 (0.02)*** |
| **LifeCycleParents w/ children** | -0.04 (0.02)* | 0.03 (0.02) |
| **LifeCycleSingle** | -0.20 (0.02)*** | -0.24 (0.02)*** |
| **D1B** | -0.01 (0.00)*** | -0.00 (0.00)*** |
| **D2A_EPHHM** | -0.14 (0.02)*** | |
| **D1B:D2A_EPHHM** | 0.00 (0.01) | |
| **FwyLaneMiPC** | | 111.72 (19.82)*** |
| **D2A_WRKEMP** | | -0.00 (0.00)*** |
| **D3bpo4** | | -0.00 (0.00)*** |
| **TranRevMiPC:D4c** | | -0.01 (0.00)*** |
| **$R^2$** | 0.47 | 0.46 |
| **Adj. $R^2$** | 0.47 | 0.46 |
| **Num. obs.** | 50399 | 40369 |
| **RMSE** | 0.90 | 1.05 |

$^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$

**Table 3.5 Prediction Accuracy of AADVMT Model**

| | rmse | nrmse | r2 |
|---|---|---|---|
| **non_metro** | 32.3 | 0.524 | 0.438 |
| **metro** | 29.3 | 0.554 | 0.432 |

### 3.3.2 Person Miles Traveled (PMT) Models

PMT Models model PMT for the three non-driving modes: transit, bike, and walk. Since there is a predominant number of zeros in non-driving PMT, hurdle model is used to model them as it captures both the zero and non-zero data generation processes in a single model structure.

#### *3.3.2.1 Transit Person Miles Traveled Model (hurdle model)*

Figure 3.1 shows a histogram of Transit Person Mile Traveled (power-transformed), as it can be seen that its distribution is much skewed towards 0.

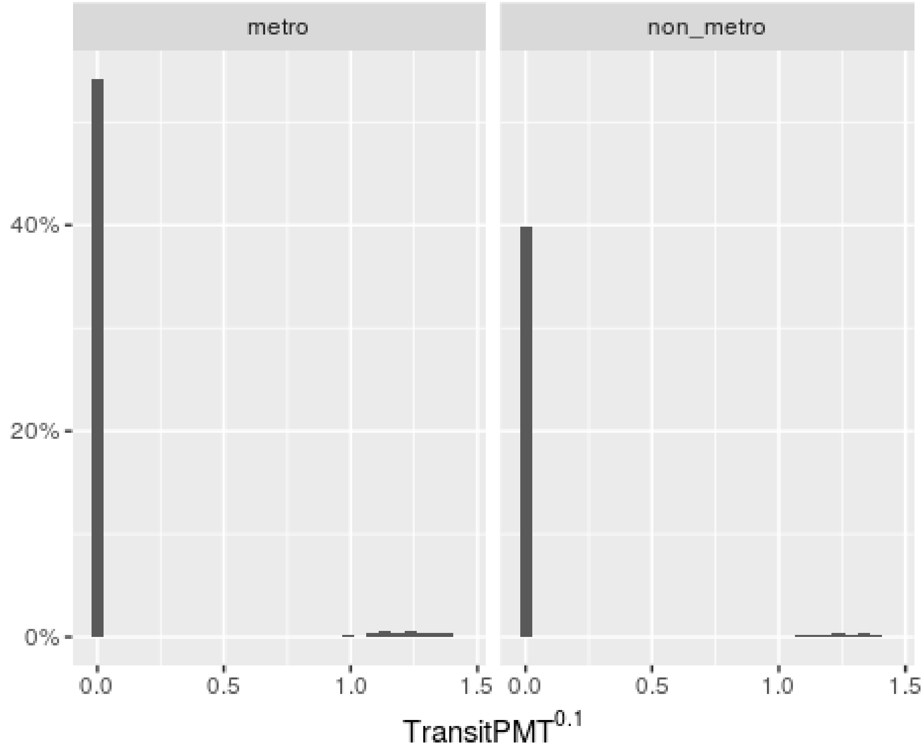


**Figure 3.1 Histogram of power-transformed transit person miles per household for metro and non-metro residents**

Table 3.6 and Table 3.7 shows the estimated model specification and accuracy of model predictions, respectively.

**Table 3.6 Transit PMT Hurdle Model**

| | **non_metro** | **metro** |
|---|---|---|
| **Count model: (Intercept)** | 3.24 (0.02)*** | 3.33 (0.02)*** |
| **Count model: AADVMT** | 0.00 (0.00)*** | 0.00 (0.00)*** |
| **Count model: HhSize** | 0.25 (0.00)*** | |
| **Count model: VehPerDriver** | 0.15 (0.01)*** | -0.35 (0.01)*** |
| **Count model: LifeCycleEmpty Nester** | -0.52 (0.03)*** | -0.03 (0.01) |
| **Count model: LifeCycleParents w/ children** | -1.21 (0.02)*** | -0.05 (0.01)*** |
| **Count model: LifeCycleSingle** | -0.15 (0.04)*** | -0.17 (0.02)*** |
| **Count model: Age0to14** | -0.10 (0.00)*** | -0.07 (0.00)*** |
| **Count model: Age65Plus** | 0.05 (0.01)*** | |
| **Count model: CENSUS_RNE** | -0.01 (0.01) | 0.12 (0.01)*** |
| **Count model: CENSUS_RS** | -0.03 (0.01)** | 0.07 (0.01)*** |
| **Count model: CENSUS_RW** | -0.40 (0.01)*** | -0.12 (0.01)*** |
| **Count model: D1B** | -0.01 (0.00)** | 0.00 (0.00)*** |
| **Count model: D3bpo4** | -0.00 (0.00) | -0.00 (0.00)*** |
| **Count model: D1B:D2A_EPHHM** | -0.08 (0.01)*** | |
| **Zero model: (Intercept)** | -4.55 (0.07)*** | -3.61 (0.07)*** |
| **Zero model: AADVMT** | 0.00 (0.00)*** | -0.01 (0.00)*** |
| **Zero model: Workers** | 0.15 (0.03)*** | 0.43 (0.02)*** |
| **Zero model: HhSize** | 0.50 (0.02)*** | |
| **Zero model: Age0to14** | 0.49 (0.03)*** | 0.33 (0.02)*** |
| **Zero model: CENSUS_RNE** | 0.02 (0.07) | -0.09 (0.05) |
| **Zero model: CENSUS_RS** | -0.20 (0.05)*** | 0.11 (0.05)* |
| **Zero model: CENSUS_RW** | -0.42 (0.07)*** | -0.51 (0.05)*** |
| **Zero model: D3bpo4** | -0.00 (0.00) | 0.00 (0.00)** |
| **Zero model: D1B** | -0.06 (0.02)*** | |
| **Zero model: D1B:D2A_EPHHM** | 0.03 (0.03) | 0.02 (0.00)*** |
| **Count model: Workers** | | 0.03 (0.00)*** |
| **Count model: D2A_EPHHM** | | 0.12 (0.02)*** |
| **Count model: FwyLaneMiPC** | | -422.06 (17.23)*** |
| **Count model: TranRevMiPC** | | 5.06 (0.29)*** |
| **Count model: D4c** | | 0.00 (0.00)*** |
| **Count model: D5** | | -0.02 (0.00)*** |
| **Zero model: LifeCycleEmpty Nester** | | -0.65 (0.07)*** |
| **Zero model: LifeCycleParents w/ children** | | 1.07 (0.05)*** |
| **Zero model: LifeCycleSingle** | | -0.37 (0.07)*** |
| **Zero model: D5** | | 0.02 (0.00)*** |
| **Zero model: TranRevMiPC** | | 23.86 (1.29)*** |
| **Zero model: TranRevMiPC:D4c** | | 0.04 (0.00)*** |
| **AIC** | 109757.79 | 163781.13 |
| **Log Likelihood** | -54852.89 | -81857.56 |
| **Num. obs.** | 49821 | 40756 |

$^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$

**Table 3.7 Prediction Accuracy of Transit PMT Model**

| | rmse | nrmse | r2 |
|---|---|---|---|
| **non_metro** | 9.49 | 7.04 | 0.0315 |
| **metro** | 8.7 | 6.27 | 0.0357 |

### *3.3.2.2 Walk Miles Traveled Model (hurdle model)*

Figure 3.2 shows a histogram of Walking Person Mile Traveled (power-transformed), as it can be seen that its distribution is very skewed towards 0.

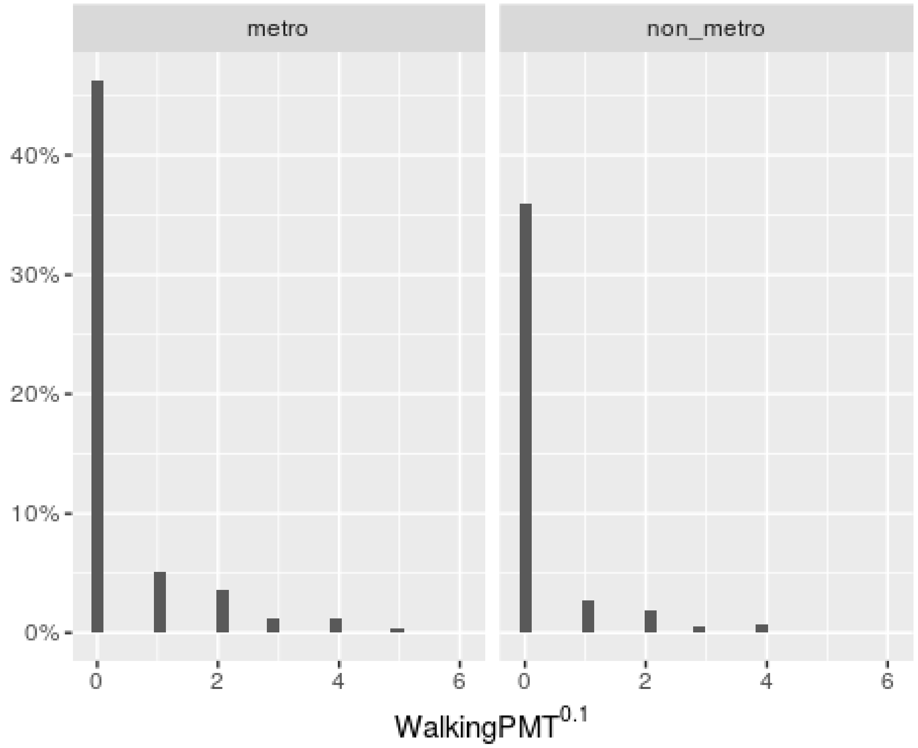


**Figure 3.2 Histogram of power-transformed walking person miles per household for metro and non-metro residents**

Table 3.8 and Table 3.9 shows the estimated model specification and accuracy of model predictions, respectively.

**Table 3.8 Walking PMT Hurdle Model**

| | non_metro | metro |
|---|---|---|
| **Count model: (Intercept)** | 0.28 (0.05)*** | 0.46 (0.04)*** |
| **Count model: AADVMT** | 0.00 (0.00)*** | 0.00 (0.00)*** |
| **Count model: HhSize** | 0.08 (0.01)*** | |
| **Count model: VehPerDriver** | -0.00 (0.02) | -0.12 (0.02)*** |
| **Count model: LifeCycleEmpty Nester** | 0.03 (0.03) | -0.09 (0.03)*** |
| **Count model: LifeCycleParents w/ children** | -0.10 (0.03)** | -0.07 (0.02)*** |
| **Count model: LifeCycleSingle** | 0.08 (0.04)* | -0.42 (0.03)*** |
| **Count model: Age0to14** | 0.02 (0.01) | 0.14 (0.01)*** |
| **Count model: Age65Plus** | -0.16 (0.02)*** | |
| **Count model: CENSUS_RNE** | -0.11 (0.03)*** | 0.01 (0.02) |
| **Count model: CENSUS_RS** | -0.09 (0.03)*** | -0.02 (0.02) |
| **Count model: CENSUS_RW** | 0.16 (0.03)*** | 0.08 (0.02)*** |
| **Count model: D1B** | -0.00 (0.01) | 0.00 (0.00)*** |
| **Count model: D3bpo4** | -0.00 (0.00)** | 0.00 (0.00)*** |
| **Count model: D1B:D2A_EPHHM** | 0.03 (0.01)** | |
| **Zero model: (Intercept)** | -3.94 (0.19)*** | -1.49 (0.05)*** |
| **Zero model: AADVMT** | -0.00 (0.00) | -0.00 (0.00)*** |
| **Zero model: Workers** | 0.01 (0.02) | 0.19 (0.02)*** |
| **Zero model: LogIncome** | 0.20 (0.02)*** | |
| **Zero model: HhSize** | 0.18 (0.01)*** | |
| **Zero model: Age0to14** | 0.02 (0.02) | 0.17 (0.02)*** |
| **Zero model: CENSUS_RNE** | 0.15 (0.04)*** | 0.01 (0.03) |
| **Zero model: CENSUS_RS** | -0.13 (0.03)*** | -0.05 (0.03) |
| **Zero model: CENSUS_RW** | 0.44 (0.04)*** | 0.19 (0.03)*** |
| **Zero model: D3bpo4** | 0.00 (0.00)*** | 0.00 (0.00)*** |
| **Zero model: D5** | 0.05 (0.02)* | 0.04 (0.00)*** |
| **Count model: Workers** | | 0.08 (0.01)*** |
| **Count model: D2A_EPHHM** | | -0.06 (0.03) |
| **Count model: FwyLaneMiPC** | | -125.50 (32.18)*** |
| **Count model: D5** | | 0.01 (0.00)*** |
| **Count model: TranRevMiPC:D4c** | | 0.00 (0.00) |
| **Zero model: LifeCycleEmpty Nester** | | -0.22 (0.04)*** |
| **Zero model: LifeCycleParents w/ children** | | 0.45 (0.03)*** |
| **Zero model: LifeCycleSingle** | | -0.40 (0.04)*** |
| **Zero model: TranRevMiPC** | | 11.22 (0.86)*** |
| **Zero model: D1B:D2A_EPHHM** | | 0.02 (0.00)*** |
| **AIC** | 68027.72 | 108981.79 |
| **Log Likelihood** | -33987.86 | -54459.90 |
| **Num. obs.** | 45985 | 40467 |

***p < 0.001, **p < 0.01, *p < 0.05

**Table 3.9 Prediction Accuracy of Walking PMT Model**

| | rmse | nrmse | r2 |
|---|---|---|---|
| **non_metro** | 1.13 | 2.97 | 0.0209 |
| **metro** | 1.38 | 2.57 | 0.0411 |

### *3.3.2.3 Bike Miles Traveled Model (hurdle model)*

Figure 3.3 shows a histogram of Biking Person Mile Traveled (power-transformed), as it can be seen that its distribution is very skewed towards 0.

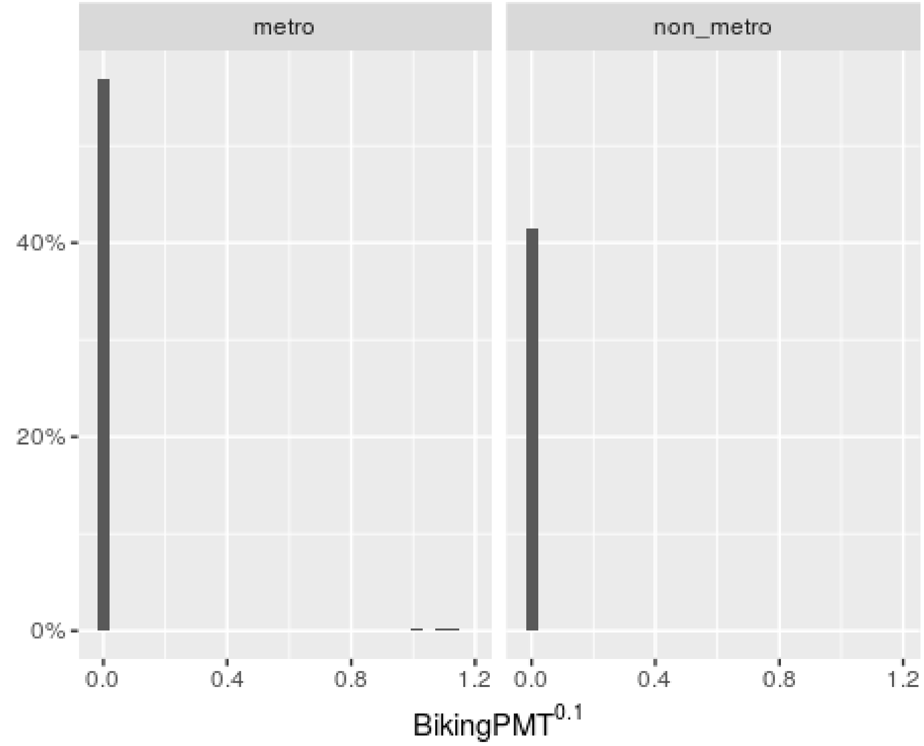


**Figure 3.3 Histogram of power-transformed biking person miles per household for metro and non-metro residents**

Table 3.10 and Table 3.11 show the estimated model specification and accuracy of model predictions, respectively.

**Table 3.10 Biking PMT Hurdle Model**

| | non_metro | metro |
|---|---|---|
| **Count model: (Intercept)** | 2.05 (0.05)*** | 1.82 (0.07)*** |
| **Count model: AADVMT** | 0.00 (0.00)*** | 0.00 (0.00)*** |
| **Count model: HhSize** | 0.10 (0.01)*** | |
| **Count model: LifeCycleEmpty Nester** | -0.36 (0.05)*** | -0.43 (0.04)*** |
| **Count model: LifeCycleParents w/ children** | -0.85 (0.04)*** | -0.50 (0.03)*** |
| **Count model: LifeCycleSingle** | -0.39 (0.05)*** | -0.35 (0.05)*** |
| **Count model: Age0to14** | -0.27 (0.02)*** | -0.17 (0.01)*** |
| **Count model: Age65Plus** | 0.15 (0.03)*** | |
| **Count model: D1B** | 0.04 (0.01)*** | 0.01 (0.00)*** |
| **Count model: D3bpo4** | 0.00 (0.00)*** | |
| **Count model: D1B:D2A_EPHHM** | -0.09 (0.01)*** | -0.03 (0.00)*** |
| **Zero model: (Intercept)** | -4.43 (0.14)*** | -3.38 (0.15)*** |
| **Zero model: AADVMT** | -0.00 (0.00)*** | -0.00 (0.00)*** |
| **Zero model: Workers** | 0.10 (0.04)* | 0.33 (0.04)*** |
| **Zero model: LifeCycleEmpty Nester** | 0.17 (0.13) | -0.37 (0.12)** |
| **Zero model: LifeCycleParents w/ children** | 1.19 (0.10)*** | 0.56 (0.08)*** |
| **Zero model: LifeCycleSingle** | -0.15 (0.14) | -0.85 (0.13)*** |
| **Zero model: Age0to14** | 0.34 (0.03)*** | 0.41 (0.03)*** |
| **Zero model: D1B** | 0.02 (0.01)* | -0.01 (0.00)*** |
| **Zero model: D2A_EPHHM** | 0.24 (0.14) | |
| **Zero model: D3bpo4** | 0.00 (0.00)*** | |
| **Zero model: D5** | -0.04 (0.07) | 0.03 (0.01)*** |
| **Count model: Workers** | | 0.10 (0.01)*** |
| **Count model: VehPerDriver** | | -0.00 (0.02) |
| **Count model: CENSUS_RNE** | | -0.01 (0.04) |
| **Count model: CENSUS_RS** | | 0.19 (0.03)*** |
| **Count model: CENSUS_RW** | | 0.24 (0.03)*** |
| **Count model: D2A_EPHHM** | | 0.17 (0.06)** |
| **Count model: FwyLaneMiPC** | | -187.80 (51.23)*** |
| **Count model: D4c** | | -0.00 (0.00)*** |
| **Count model: D4c:TranRevMiPC** | | 0.15 (0.01)*** |
| **Zero model: CENSUS_RNE** | | -0.72 (0.10)*** |
| **Zero model: CENSUS_RS** | | -0.10 (0.08) |
| **Zero model: CENSUS_RW** | | 0.05 (0.07) |
| **Zero model: FwyLaneMiPC** | | -714.87 (129.69)*** |
| **Zero model: TranRevMiPC** | | -5.82 (2.57)* |
| **Zero model: D1B:D2A_EPHHM** | | 0.01 (0.01) |
| **AIC** | 20735.55 | 26350.20 |
| **Log Likelihood** | -10345.78 | -13143.10 |
| **Num. obs.** | 49821 | 40756 |

***p < 0.001, **p < 0.01, *p < 0.05

**Table 3.11 Prediction Accuracy of Biking PMT Model**

| | rmse | nrmse | r2 |
|---|---|---|---|
| **non_metro** | 4.24 | 34.8 | 0.0000000638 |
| **metro** | 2 | 10.6 | 0.000481 |

## 3.4 TRIP FREQUENCY-LENGTH (TFL) MODELS

An alternative model structure we propose is a combination of household level models of trip frequency and average trip length by mode (Figure 3.4).

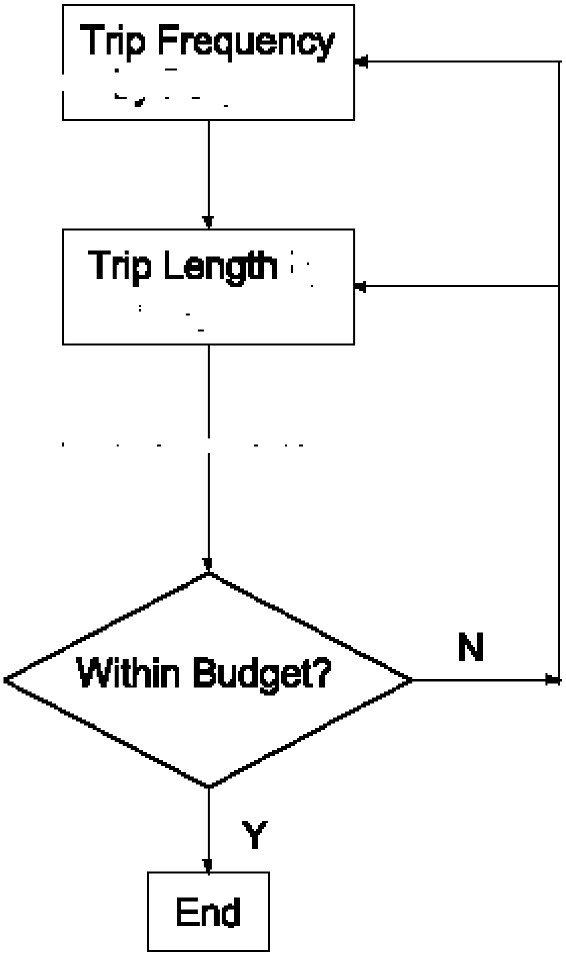


**Figure 3.4 Flow chart of trip frequency-length model**

## 3.4.1 Trip Frequency Models

The trip frequency models of Transit, Bike, and Walk are hurdle models with the dependent variable (# Trips): $(\#Trips) = zinb(X\beta)$. A hurdle model only allows zeros to arise from the zero hurdle process but not the count process. Like other models, the trip frequency models are segmented by metro and non-metro areas.

### *3.4.1.1 Transit Trip Frequency Model (Hurdle Model)*

Figure 3.5 shows a histogram of Transit Trip Frequency, as it can be seen that its distribution is much skewed towards 0.

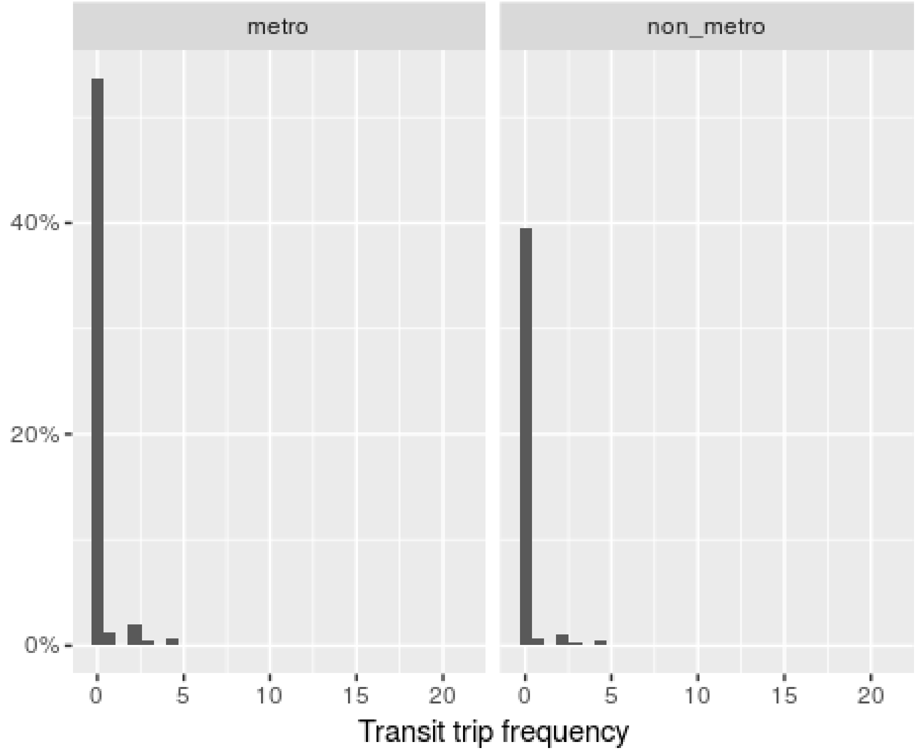


**Figure 3.5 Histogram of transit trip frequencies per household for metro and non-metro residents**

Table 3.12 and Table 3.13 show the estimated model specification and accuracy of model predictions, respectively.

**Table 3.12 Transit Trip Frequency Hurdle Model**

| | Non Metro | Metro |
|---|---|---|
| **Count model: (Intercept)** | 0.92 (0.22)*** | 0.06 (0.04) |
| **Count model: log1p(AADVMT)** | 0.01 (0.02) | |
| **Count model: log1p(VehPerDriver)** | 0.14 (0.07)* | |
| **Count model: HhSize** | 0.14 (0.01)*** | 0.14 (0.01)*** |
| **Count model: LifeCycleEmpty Nester** | 0.47 (0.13)*** | 0.04 (0.05) |
| **Count model: LifeCycleParents w/ children** | 0.04 (0.11) | 0.07 (0.04)* |
| **Count model: LifeCycleSingle** | 0.52 (0.18)** | -0.23 (0.06)*** |
| **Count model: Age0to14** | 0.19 (0.02)*** | 0.09 (0.01)*** |
| **Count model: LogIncome** | -0.10 (0.02)*** | |
| **Count model: D1B** | -0.00 (0.01) | 0.00 (0.00) |
| **Zero model: (Intercept)** | -5.28 (0.33)*** | -1.98 (0.10)*** |
| **Zero model: log1p(AADVMT)** | 0.12 (0.04)*** | |
| **Zero model: log1p(VehPerDriver)** | -0.34 (0.12)** | |
| **Zero model: Workers** | 0.04 (0.03) | 0.34 (0.02)*** |
| **Zero model: LifeCycleEmpty Nester** | -0.17 (0.15) | -0.65 (0.07)*** |
| **Zero model: LifeCycleParents w/ children** | 2.61 (0.11)*** | 0.88 (0.05)*** |
| **Zero model: LifeCycleSingle** | -0.65 (0.21)** | -0.10 (0.07) |
| **Zero model: Age0to14** | 0.47 (0.02)*** | 0.29 (0.02)*** |
| **Zero model: D1B** | -0.07 (0.01)*** | 0.01 (0.00)*** |
| **Zero model: D3bpo4** | 0.00 (0.00) | |
| **Zero model: LogIncome** | 0.05 (0.03) | |
| **Count model: AADVMT** | | -0.00 (0.00)*** |
| **Count model: TranRevMiPC** | | 5.34 (0.72)*** |
| **Count model: D4c** | | 0.00 (0.00)*** |
| **Zero model: AADVMT** | | -0.00 (0.00)*** |
| **Zero model: VehPerDriver** | | -1.43 (0.06)*** |
| **Zero model: HhSize** | | 0.09 (0.02)*** |
| **Zero model: FwyLaneMiPC** | | -39.06 (69.88) |
| **Zero model: TranRevMiPC:D4c** | | 0.05 (0.00)*** |
| **AIC** | 24301.11 | 44355.93 |
| **Log Likelihood** | -12129.55 | -22155.96 |
| **Num. obs.** | 45985 | 40467 |

$^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$

**Table 3.13 Prediction Accuracy of Transit Trip Frequency Model**

| | rmse | nrmse | r2 |
|---|---|---|---|
| **non_metro** | 0.673 | 4.7 | 0.143 |
| **metro** | 0.701 | 4.48 | 0.104 |

### *3.4.1.2 Walking Trip Frequency Model (Hurdle Model)*

Figure 3.6 shows a histogram of Walking Trip Frequency, as it can be seen that its distribution is much skewed towards 0.

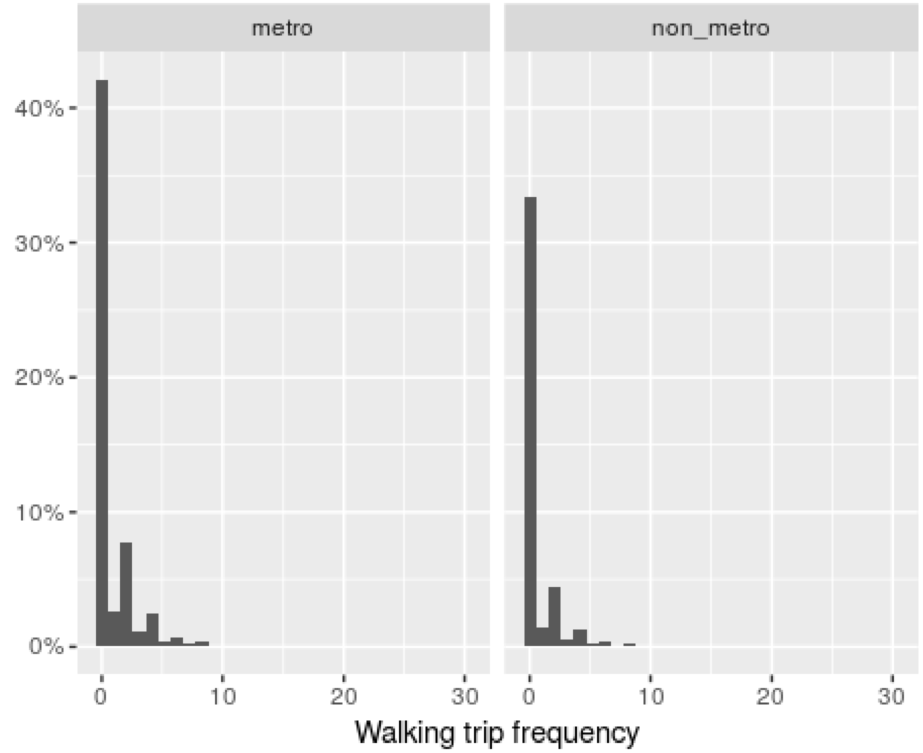


**Figure 3.6 Histogram of walking trip frequencies per household for metro and non-metro residents**

Table 3.14 and Table 3.15 show the estimated model specification and accuracy of model predictions, respectively.

**Table 3.14 Walking Trip Frequency Hurdle Model**

| | non_metro | Metro |
|---|---|---|
| **Count model: (Intercept)** | 0.33 (0.11)** | 0.44 (0.08)*** |
| **Count model: AADVMT** | -0.00 (0.00)*** | -0.00 (0.00) |
| **Count model: VehPerDriver** | 0.00 (0.01) | -0.11 (0.01)*** |
| **Count model: HhSize** | 0.07 (0.01)*** | 0.07 (0.01)*** |
| **Count model: LifeCycleEmpty Nester** | -0.13 (0.02)*** | -0.14 (0.02)*** |
| **Count model: LifeCycleParents w/ children** | -0.04 (0.02) | -0.13 (0.02)*** |
| **Count model: LifeCycleSingle** | -0.08 (0.03)** | -0.28 (0.02)*** |
| **Count model: Age0to14** | 0.07 (0.01)*** | 0.13 (0.01)*** |
| **Count model: D1B** | 0.02 (0.00)*** | 0.00 (0.00)*** |
| **Count model: D2A_EPHHM** | 0.28 (0.03)*** | 0.25 (0.02)*** |
| **Count model: D3bpo4** | -0.00 (0.00) | 0.00 (0.00)*** |
| **Count model: D5** | -0.03 (0.01)** | 0.01 (0.00)*** |
| **Count model: Workers** | -0.08 (0.01)*** | |
| **Count model: LogIncome** | 0.05 (0.01)*** | 0.05 (0.01)*** |
| **Zero model: (Intercept)** | -4.10 (0.20)*** | -2.86 (0.17)*** |
| **Zero model: AADVMT** | -0.00 (0.00) | -0.00 (0.00)*** |
| **Zero model: VehPerDriver** | -0.09 (0.02)*** | -0.16 (0.03)*** |
| **Zero model: HhSize** | 0.20 (0.02)*** | 0.21 (0.02)*** |
| **Zero model: LifeCycleEmpty Nester** | -0.01 (0.04) | -0.23 (0.04)*** |
| **Zero model: LifeCycleParents w/ children** | -0.05 (0.04) | 0.19 (0.04)*** |
| **Zero model: LifeCycleSingle** | 0.05 (0.05) | -0.19 (0.04)*** |
| **Zero model: Age0to14** | 0.02 (0.02) | 0.04 (0.02) |
| **Zero model: D1B** | 0.04 (0.00)*** | 0.01 (0.00)*** |
| **Zero model: D2A_EPHHM** | 0.11 (0.06) | 0.24 (0.05)*** |
| **Zero model: D3bpo4** | -0.00 (0.00) | 0.00 (0.00)*** |
| **Zero model: Workers** | 0.01 (0.02) | 0.08 (0.02)*** |
| **Zero model: LogIncome** | 0.21 (0.02)*** | 0.11 (0.02)*** |
| **Count model: FwyLaneMiPC** | | -326.19 (25.28)*** |
| **Count model: TranRevMiPC** | | 0.95 (0.41)* |
| **Count model: D4c** | | 0.00 (0.00)*** |
| **Zero model: D5** | | 0.04 (0.00)*** |
| **Zero model: FwyLaneMiPC** | | -39.30 (45.48) |
| **Zero model: TranRevMiPC** | | 10.13 (0.85)*** |
| **Zero model: D4c** | | 0.00 (0.00)*** |
| **AIC** | 74022.13 | 113601.76 |
| **Log Likelihood** | -36984.07 | -56767.88 |
| **Num. obs.** | 45985 | 37547 |

$^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$

**Table 3.15 Prediction Accuracy of Walking Trip Frequency Model**

| | rmse | nrmse | r2 |
|---|---|---|---|
| **non_metro** | 1.45 | 2.48 | 0.0259 |
| **metro** | 1.77 | 2.17 | 0.0782 |

### *3.4.1.3 Biking Trip Frequency Model (Hurdle Model)*

Figure 3.7 shows a histogram of Biking Trip Frequency, as it can be seen that its distribution is very skewed towards 0.

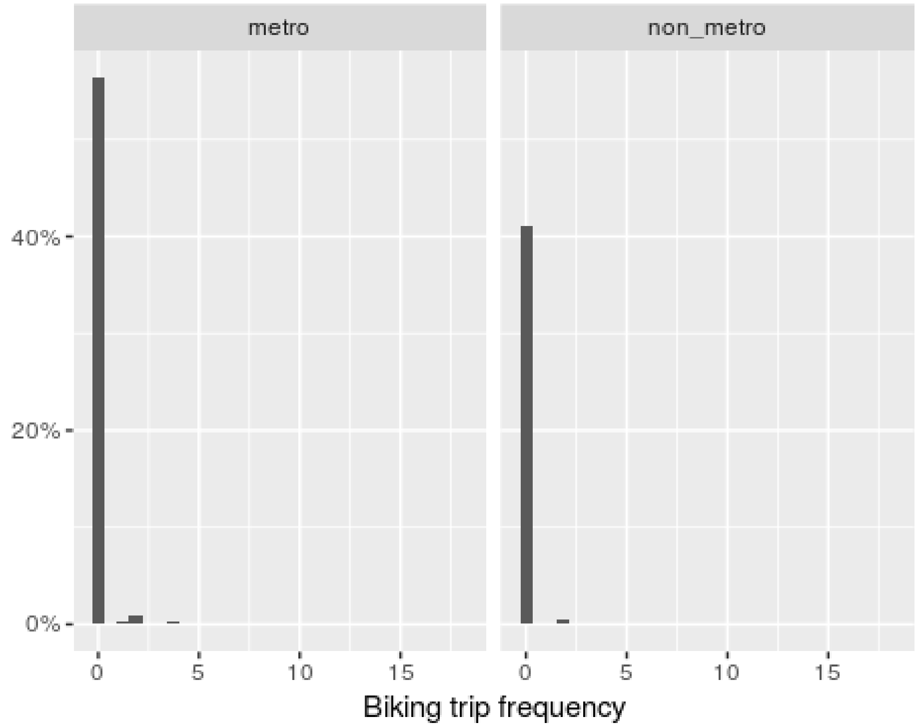


**Figure 3.7 Histogram of biking trip frequencies per household for metro and non-metro residents**

Table 3.16 and Table 3.17 show the estimated model specification and accuracy of model predictions, respectively.

**Table 3.16 Biking Trip Frequency Hurdle Model**

| | non_metro | Metro |
|---|---|---|
| **Count model: (Intercept)** | 0.28 (0.32) | 1.22 (0.23)*** |
| **Count model: AADVMT** | -0.00 (0.00)*** | -0.00 (0.00)*** |
| **Count model: VehPerDriver** | -0.14 (0.05)** | |
| **Count model: HhSize** | 0.13 (0.03)*** | |
| **Count model: LifeCycleEmpty Nester** | -0.14 (0.09) | |
| **Count model: LifeCycleParents w/ children** | -0.34 (0.08)*** | |
| **Count model: LifeCycleSingle** | -0.38 (0.11)*** | |
| **Count model: Age0to14** | 0.01 (0.03) | 0.14 (0.02)*** |
| **Count model: Age65Plus** | -0.02 (0.05) | 0.09 (0.03)** |
| **Count model: D1B** | -0.03 (0.01)*** | -0.00 (0.00)* |
| **Count model: Workers** | -0.14 (0.03)*** | -0.02 (0.02) |
| **Count model: LogIncome** | 0.08 (0.03)** | -0.01 (0.02) |
| **Count model: D3bpo4** | 0.01 (0.00)*** | 0.00 (0.00) |
| **Zero model: (Intercept)** | -7.86 (0.50)*** | -5.00 (0.39)*** |
| **Zero model: AADVMT** | -0.01 (0.00)*** | |
| **Zero model: VehPerDriver** | 0.08 (0.06) | |
| **Zero model: LifeCycleEmpty Nester** | 0.33 (0.14)* | -0.31 (0.11)** |
| **Zero model: LifeCycleParents w/ children** | 1.24 (0.11)*** | 0.61 (0.08)*** |
| **Zero model: LifeCycleSingle** | -0.09 (0.15) | -0.56 (0.11)*** |
| **Zero model: Age0to14** | 0.31 (0.03)*** | 0.38 (0.03)*** |
| **Zero model: Age65Plus** | -0.12 (0.07) | 0.04 (0.06) |
| **Zero model: D2A_EPHHM** | 0.21 (0.14) | 0.02 (0.10) |
| **Zero model: D5** | 0.01 (0.05) | |
| **Zero model: Workers** | 0.03 (0.04) | 0.25 (0.04)*** |
| **Zero model: LogIncome** | 0.33 (0.05)*** | 0.18 (0.04)*** |
| **Zero model: D3bpo4** | 0.01 (0.00)*** | 0.00 (0.00) |
| **Zero model: log1p(AADVMT)** | | -0.17 (0.03)*** |
| **Zero model: HhSize** | | 0.04 (0.03) |
| **Zero model: FwyLaneMiPC** | | -464.20 (87.23)*** |
| **Zero model: TranRevMiPC** | | -15.31 (2.08)*** |
| **AIC** | 13826.58 | 23367.31 |
| **Log Likelihood** | -6887.29 | -11661.66 |
| **Num. obs.** | 46665 | 57362 |

$^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$

**Table 3.17 Prediction Accuracy of Biking Trip Frequency Model**

| | rmse | nrmse | r2 |
|---|---|---|---|
| **non_metro** | 0.432 | 7.93 | 0.00887 |
| **metro** | 0.554 | 6.85 | 0.0199 |

## 3.4.2 Average Trip Length Models

The average trip length models are linear regression models with the dependent variable (TRPMILES) power-transformed: $TRIPMILES^{0.10} = X\beta$. These models are similar in model structure to the non-zero DVMT model in GreenSTEP, but for average trip length for Transit, Bike and Walk trips.

The TFL model option is simplified from the original Trip Frequency-Length-Mode (TFLM) Model, which models individual trips for each household in the sample. One of the reasons for this simplification was performance: even though it has advantages in that it allows trip information to be utilized in these models, for example, trip purpose and trip length, which are important factors in mode choice decision. In the estimation of TFLM model with NHTS data, it needs to use the trip dataset, which has more than 1 million observations; while in simulation, it requires to create a dataset with one observation for every trip. Even though it can work, the requirement for memory and the penalty of speed are high. We eventually settle with the simplified TFL model that captures the essential of travel demand for non-driving modes.

### *3.4.2.1 Transit Trip Length Model*

Figure 3.8 shows a histogram of Average Transit Trip Length for households making at least one transit trips.

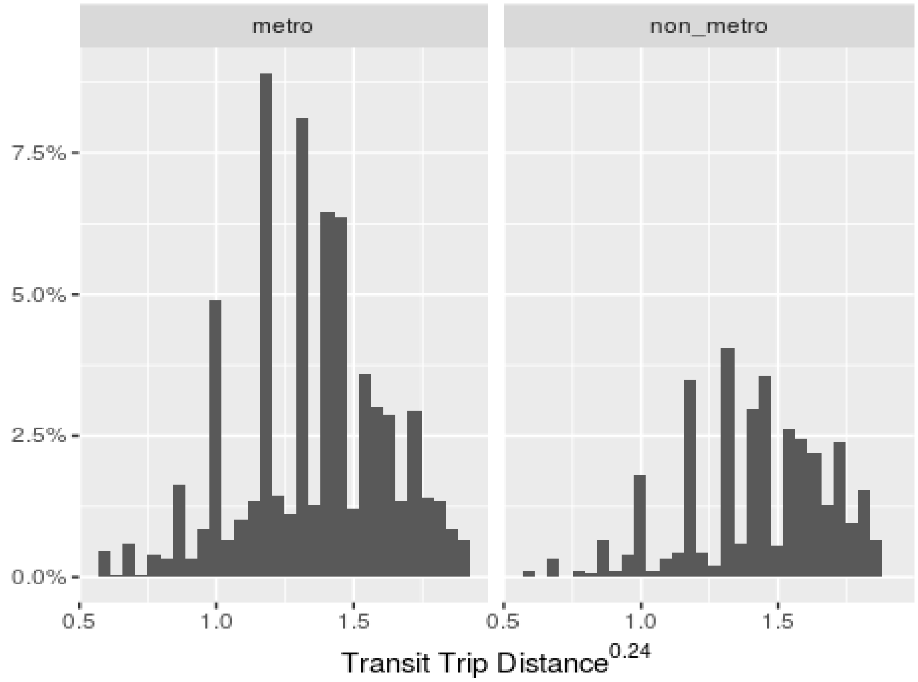


**Figure 3.8 Histogram of power-transformed transit trip distance per household for metro and non-metro residents**

Table 3.18 and Table 3.19 show the estimated model specification and accuracy of model predictions, respectively.

**Table 3.18 Power-transformed Average Transit Trip Length Regression Model**

| | **non_metro** | **Metro** |
|---|---|---|
| **(Intercept)** | 1.92 (0.31)*** | 0.15 (0.29) |
| **AADVMT** | 0.00 (0.00)*** | 0.00 (0.00) |
| **Age0to14** | -0.19 (0.02)*** | -0.23 (0.03)*** |
| **Age65Plus** | 0.17 (0.06)** | 0.28 (0.06)*** |
| **LogIncome** | 0.07 (0.03)** | 0.14 (0.03)*** |
| **LifeCycleEmpty Nester** | -0.90 (0.15)*** | -0.59 (0.11)*** |
| **LifeCycleParents w/ children** | -0.77 (0.11)*** | 0.03 (0.06) |
| **LifeCycleSingle** | -0.71 (0.21)*** | 0.10 (0.10) |
| **D2A_EPHHM** | -0.30 (0.09)*** | -0.07 (0.09) |
| **D1B** | -0.07 (0.01)*** | -0.00 (0.00) |
| **D5** | 0.10 (0.04)** | -0.01 (0.00)*** |
| **VehPerDriver** | | -0.25 (0.06)*** |
| **D3bpo4** | | -0.00 (0.00) |
| **TranRevMiPC** | | 6.68 (1.55)*** |
| **TranRevMiPC:D4c** | | -0.00 (0.01) |
| **R2** | 0.10 | 0.09 |
| **Adj. R2** | 0.10 | 0.08 |
| **Num. obs.** | 2653 | 2744 |
| **RMSE** | 0.99 | 1.37 |

***p < 0.001, **p < 0.01, *p < 0.05

**Table 3.19 Prediction Accuracy of Average Transit Trip Length Model**

| | **rmse** | **nrmse** |
|---|---|---|
| **non_metro** | 9.37 | 18.3 |
| **metro** | 5.35 | 10.6 |

### *3.4.2.2 Walking Trip Length Model*

Figure 3.9 shows a histogram of Average Walking Trip Length for households making at least one walking trip.

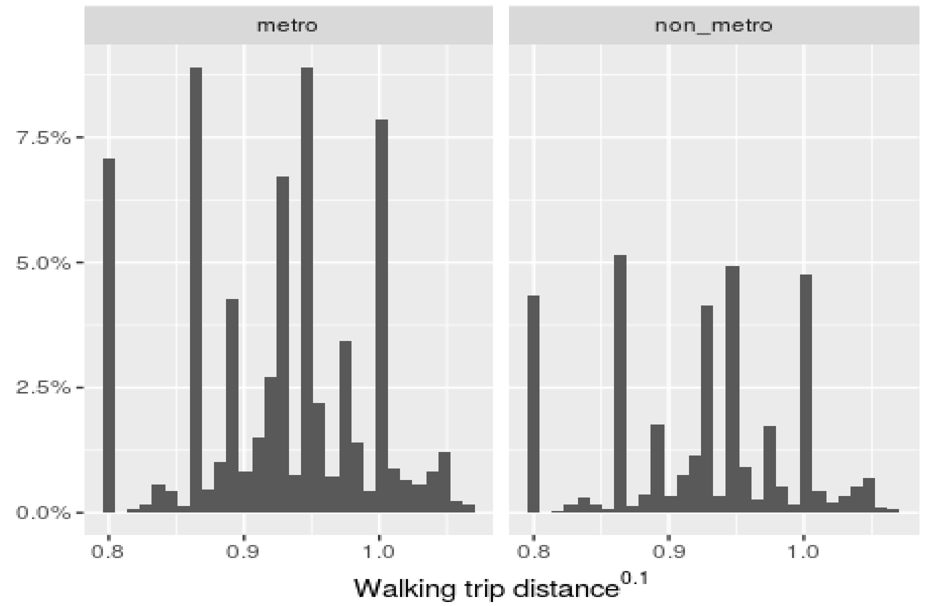


**Figure 3.9 Histogram of average walking trip distance per household for metro and non-metro residents**

Table 3.20 and Table 3.21 show the estimated model specification and accuracy of model predictions, respectively.

**Table 3.20 Power-transformed Average Walking Trip Length Regression Model**

| | **non_metro** | **Metro** |
|---|---|---|
| **(Intercept)** | -1.60 (0.13)*** | -1.12 (0.12)*** |
| **AADVMT** | 0.00 (0.00)*** | 0.00 (0.00)*** |
| **Age0to14** | -0.01 (0.01) | -0.05 (0.01)*** |
| **Age65Plus** | -0.02 (0.02) | 0.03 (0.02) |
| **LogIncome** | 0.07 (0.01)*** | 0.06 (0.01)*** |
| **LifeCycleEmpty Nester** | -0.03 (0.03) | -0.07 (0.03)* |
| **LifeCycleParents w/ children** | -0.03 (0.03) | -0.06 (0.02)* |
| **LifeCycleSingle** | -0.03 (0.03) | -0.08 (0.03)** |
| **D2A_EPHHM** | 0.08 (0.04)* | -0.22 (0.04)*** |
| **D1B** | 0.00 (0.00) | -0.00 (0.00) |
| **D5** | -0.01 (0.01) | 0.01 (0.00)*** |
| **VehPerDriver** | | -0.02 (0.02) |
| **D3bpo4** | | 0.00 (0.00) |
| **TranRevMiPC** | | -4.81 (0.64)*** |
| **TranRevMiPC:D4c** | | -0.00 (0.00) |
| **R2** | 0.01 | 0.02 |
| **Adj. R2** | 0.01 | 0.02 |
| **Num. obs.** | 9602 | 11108 |
| **RMSE** | 0.80 | 0.97 |

***p < 0.001, **p < 0.01, *p < 0.05

**Table 3.21 Prediction Accuracy of Walking Trip Length Model**

| | rmse | nrmse |
|---|---|---|
| **non_metro** | 0.523 | 3.63 |
| **metro** | 0.556 | 2.88 |

### *3.4.2.3 Biking Trip Length Model*

Figure 3.10 shows a histogram of Average Biking Trip Length for households making at least one biking trip.

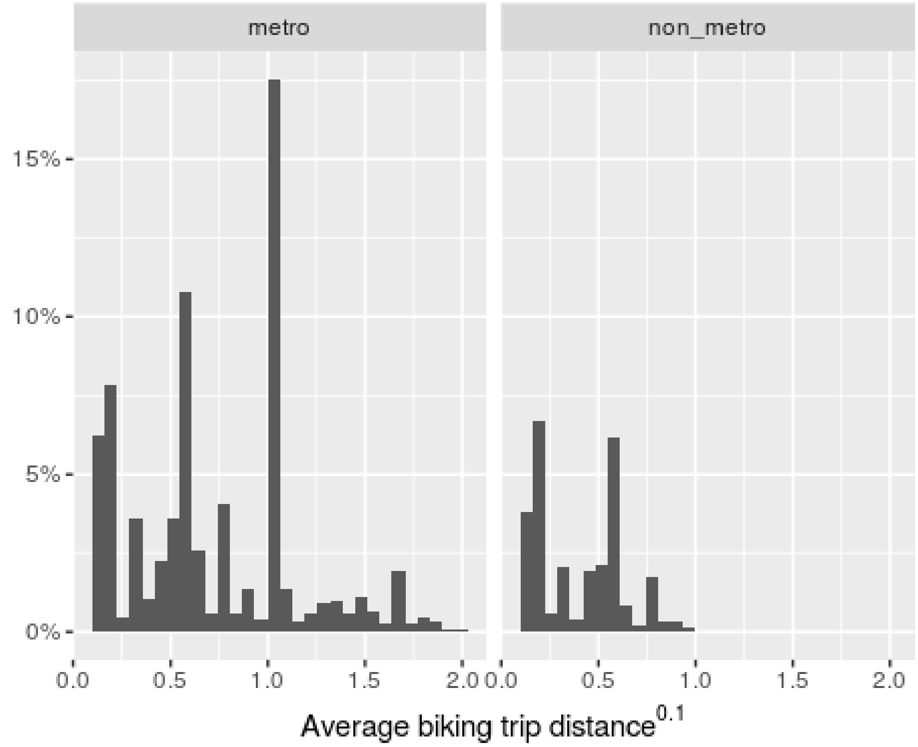


**Figure 3.10 Histogram of average biking trip distance per household for metro and non-metro residents**

Table 3.22 and Table 3.23 show the estimated model specification and accuracy of model predictions, respectively.

**Table 3.22 Power-transformed Average Biking Trip Length Regression Model**

| | non_metro | Metro |
|---|---|---|
| **(Intercept)** | -2.06 (0.52)*** | -1.16 (0.51)* |
| **AADVMT** | 0.00 (0.00) | 0.00 (0.00)*** |
| **Age0to14** | -0.21 (0.05)*** | -0.26 (0.04)*** |
| **Age65Plus** | 0.23 (0.08)** | -0.03 (0.08) |
| **LogIncome** | 0.28 (0.05)*** | 0.20 (0.04)*** |
| **LifeCycleEmpty Nester** | -0.42 (0.16)** | -0.66 (0.15)*** |
| **LifeCycleParents w/ children** | -0.86 (0.13)*** | -0.83 (0.10)*** |
| **LifeCycleSingle** | -0.55 (0.17)** | -0.15 (0.16) |
| **D2A_EPHHM** | -0.39 (0.17)* | -0.12 (0.14) |
| **D1B** | 0.05 (0.01)*** | 0.00 (0.00) |
| **D5** | 0.06 (0.09) | |
| **VehPerDriver** | | -0.20 (0.05)*** |
| **D3bpo4** | | -0.00 (0.00) |
| **TranRevMiPC** | | 3.95 (3.05) |
| **TranRevMiPC:D4c** | | 0.10 (0.02)*** |
| **R2** | 0.24 | 0.21 |
| **Adj. R2** | 0.24 | 0.20 |
| **Num. obs.** | 967 | 1254 |
| **RMSE** | 1.18 | 1.17 |

***p < 0.001, **p < 0.01, *p < 0.05

**Table 3.23 Prediction Accuracy of Biking Trip Length Model**

| | rmse | nrmse |
|---|---|---|
| **non_metro** | 2.37 | 47.3 |
| **metro** | 3.6 | 45.3 |

## 3.5 OTHER MODEL STRUCTURES CONSIDERED

### 3.5.1 Total Person Miles Traveled by Mode (TPMTM) Model

The TPMTM model is made up of two sequential models: a Total Person Miles Traveled (TPMT) and a Mode Allocation Model (Figure 3.11).

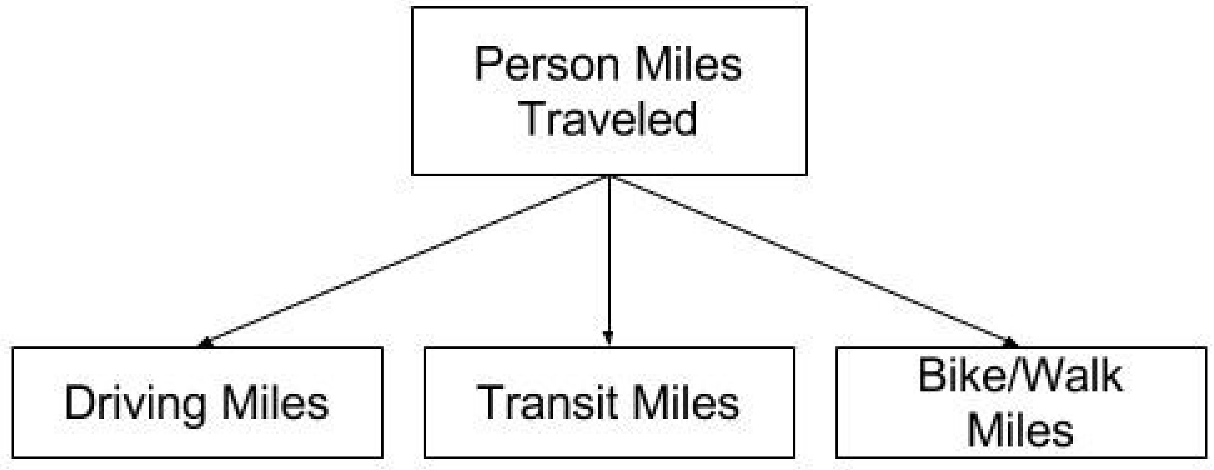


**Figure 3.11 Flow chart of total person miles by model**

The total person miles traveled is a household level model of total person miles traveled by all household members. It is a linear regression model with total PMT (log or power transformed) as the dependent variable: $\ln(pmt) = X\beta$ or $(pmt)^{\lambda} = X\beta$, while the mode allocation model captures the percentage of PMT by modes for households and allocates total PMT to each mode in prediction. In estimation, we first choose a base mode, compute the ratio of PMT percentage for all other modes relative to that for the base mode, and then use log of the ratio (i.e., log-odds ratio) as the dependent variable of the mode allocation model. We will estimate $n-1$ models if there are $n$ modes in total. In prediction, we first predict the log-odds ratios from each of the $n-1$ models, exponentiate the predicted log-odds ratios to get odds ratios, and apply the additional condition that the odds for all modes sum up to 1 to get the predicted PMT percentage for each mode. The model structure is consistent with a multinomial logit model that is commonly used in mode choice modeling.

$$\ln\left(\frac{P_{Transit}}{P_{Auto}}\right) = X\boldsymbol{\beta}, \tag{3-5}$$

$$\ln\left(\frac{P_{Bike/Walk}}{P_{Auto}}\right) = X\boldsymbol{\beta}. \tag{3-6}$$

Both models can be segmented by life stage of a household (e.g. single, young couple, full nesters, empty nesters), built environment variables or other demographics for better model fit and predicting power.

The advantage of the TPMTM model is that the model structure is similar to the existing household travel model in GreenSTEP, and consistent with mode choice models in travel demand modeling, however, the disadvantages include:

1. TPMTM is modeled at an aggregated household level and some of the traveler/trip information that is useful for mode choice modeling is lost. For example, a household will likely have a different probability of choosing walking for 2 trips of half mile each than for 1 trip of 1 mile.

2. The NHTS data is dominated by driving when mode shares are measured by distance. The small share of transit and bike/walk mode may bring large variance of the odds ratio variable.

Finally, special handling is required when any of the shares are 0 among the modes being modeled (Auto, Transit, Bike, Walk), which is common for daily travel.

## 3.6 COMPARISON OF MODEL APPROACHES FOR NON-AUTO MODES

After reporting to the TAC in October 2016, we converged to suspend the work on TPMTM models and focus on PMT and TFL models, which are subsequently implemented. These two alternate non-auto model approaches were pursued through implementation and testing.

Statistical significance, theoretical foundation, and predicting power: because of the large sample size (n>15,000) of 2009 NHTS, it is easy to get a large number of significant coefficients, but they do not necessarily make for a good predictive model. On the other hand, models solely focusing on predictive power (for example, those based on machine learning algorithms) may lack theoretical basis thus may break down when predicting outcomes for conditions far from the base year range. One thing that is particularly hard to do for predictive models is for them to capture behavior that has not been observed in data, for example, potential non-linearity of price elasticities when price rise.

# 4.0 MODEL TESTING

## 4.1 TASK DESCRIPTION

PSU researchers shall apply the newly incorporated mode shift module (in the updated RSPM tool) in the Rouge Valley Metropolitan Planning Organization (RVMPO) to assess how it can inform decision-making and to adjust the model as needed to provide accurate and helpful information. ODOT staff will assist in assembling the necessary data for sensitivity tests. Initial testing will be documented by the PSU researchers.

The phases of the testing task are:

**Phase 1**: Test modules on their own using SLD/NHTS data used in estimation; Test module sensitivity, vary SLD/NHTS inputs one at a time – elasticity response vs. Literature VMT, PMT by mode, total and split by HH income, density, urban form groups

**Phase 2**: Test module in RVMPO RSPM (using a code wrapper and supplemental RVMPO block group place type inputs) comparing current vs. new outputs, VMT/Alt mode trips at MPO/district geographies (maps) and HH attributes (place types, income, …) – tests full model performance improvement over existing tool using built form variables

**Phase 3**: Test module in VisionEval (written up to the 1st call of this module) – tests to see if the module will work in future VisionEval tool

All models estimated in Chapter 3 except for Trip Length Regression Models for Transit, Bike and Walk are tested for sensitivities below. The elasticities are compared with the DVMT model in GreenSTEP and with those reported in the literature.

## 4.2 PHASE I

For Phase I of Task 4, elasticities of AADVMT and PMT with regard to density (D1B), household income, freeway supply (Freeway lane miles per capita), transit supply (transit revenue miles per capita) are computed using the 2009 data. Except for a few unexpected counterintuitive directions of elasticities (bike PMT elasticities wrt D1B), the elasticities are in line with what has been documented in the research literature: travel behavior responses to density change is small in magnitude. Given the non-linear nature of the models, the elasticities vary by different segments - such as income group, development type, and current density level. Those segments are adopted from what Brian Gregor used in his sensitivity testing for GreenSTEP.

### 4.2.1 Annual Average Daily VMT (AADVMT)

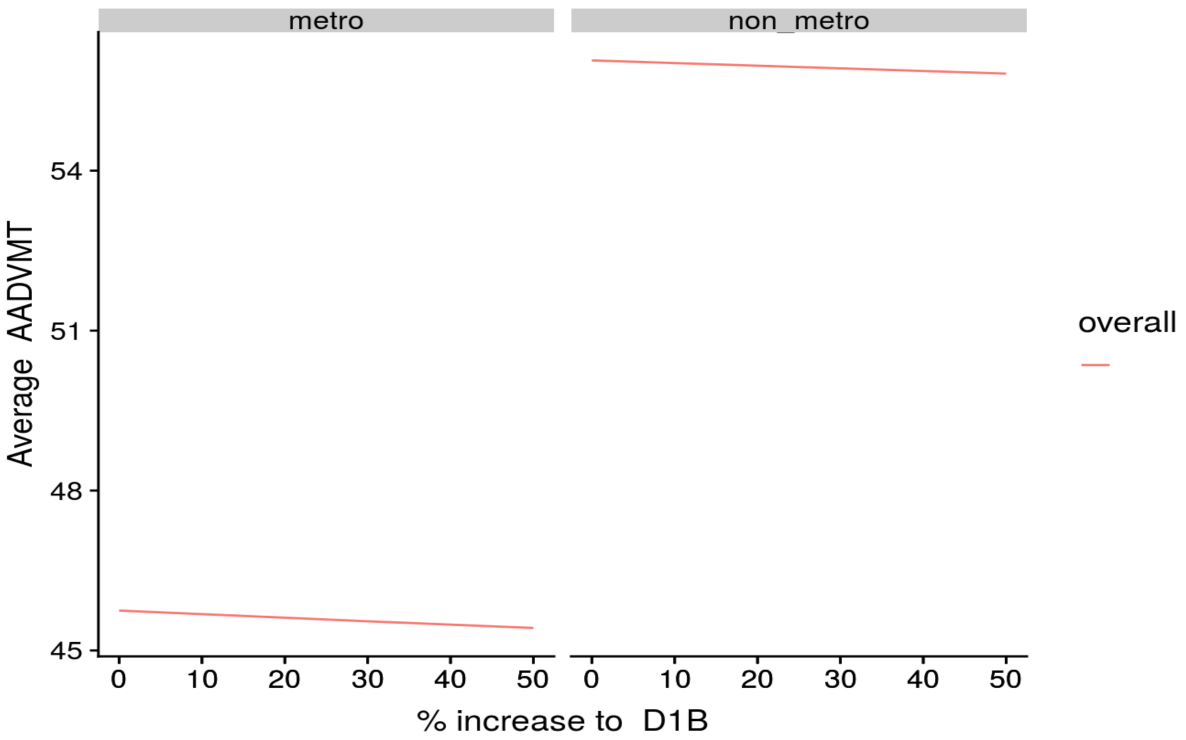
The specification for the AADVMT model is available in Chapter 3 AADVMT Model Specification.

#### *4.2.1.1 Population Density (D1B) Sensitivity*

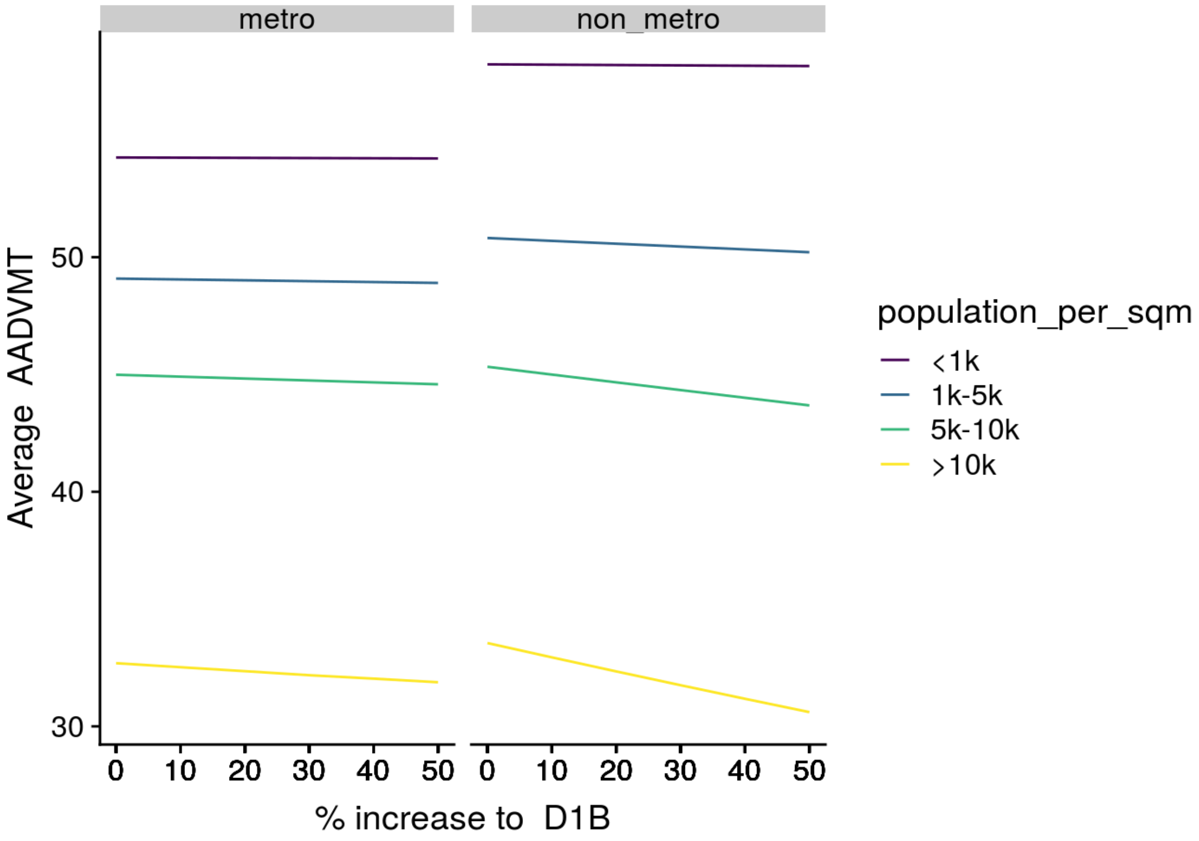
Both Table 4.1 and Figure 4.1 below demonstrate small negative elasticities of AADVMT to local population density (D1B from Smart Location Database population density at block group level). Non-metropolitan areas have larger elasticities; higher density areas have larger elasticities, and TODs have larger elasticities.

**Table 4.1 Elasticities of AADVMT with Respect to D1B**

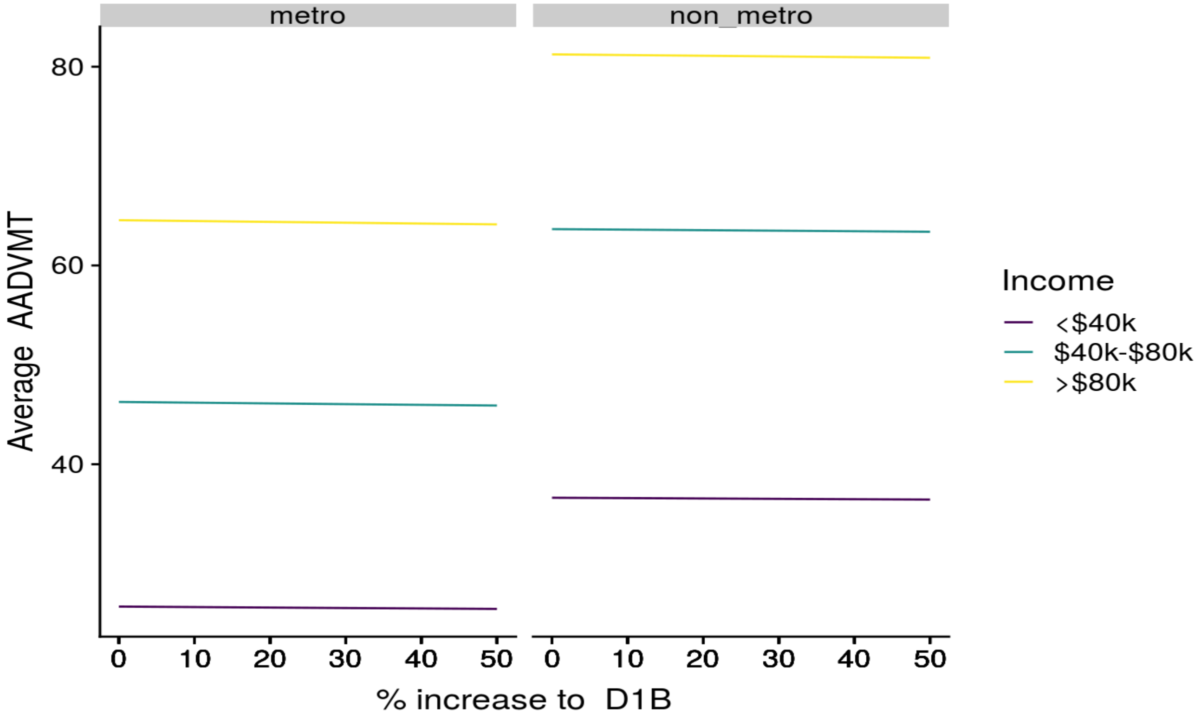
| | | | | | **Δ AADVMT wrt Δ D1B** | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **metro** | **Category** | **n** | **AADVMT** | | **+10%** | **+20%** | **+30%** | **+40%** | **+50%** |
| **Overall** | | | | | | | | | |
| **metro** | | 66669 | 45.7 | | -0.067 | -0.134 | -0.202 | -0.263 | -0.327 |
| **non_metro** | | 53859 | 56.1 | | -0.050 | -0.100 | -0.149 | -0.199 | -0.248 |
| **population_per_sqm** | | | | | | | | | |
| **metro** | <1k | 6700 | 54.3 | | -0.008 | -0.016 | -0.025 | -0.033 | -0.041 |
| **metro** | 1k-5k | 36154 | 49.1 | | -0.037 | -0.074 | -0.112 | -0.149 | -0.186 |
| **metro** | 5k-10k | 16752 | 45.0 | | -0.082 | -0.163 | -0.245 | -0.326 | -0.407 |
| **metro** | >10k | 7063 | 32.7 | | -0.171 | -0.340 | -0.512 | -0.658 | -0.812 |
| **non_metro** | <1k | 39696 | 58.2 | | -0.014 | -0.029 | -0.043 | -0.057 | -0.072 |
| **non_metro** | 1k-5k | 12572 | 50.8 | | -0.122 | -0.243 | -0.365 | -0.486 | -0.607 |
| **non_metro** | 5k-10k | 1387 | 45.3 | | -0.333 | -0.664 | -0.993 | -1.321 | -1.647 |
| **non_metro** | >10k | 204 | 33.6 | | -0.610 | -1.208 | -1.797 | -2.376 | -2.944 |
| **income** | | | | | | | | | |
| **metro** | <$40k | 24391 | 25.7 | | -0.049 | -0.098 | -0.148 | -0.189 | -0.235 |
| **metro** | $40k-$80k | 20864 | 46.3 | | -0.074 | -0.147 | -0.220 | -0.293 | -0.362 |
| **metro** | >$80k | 21414 | 64.6 | | -0.085 | -0.170 | -0.255 | -0.339 | -0.422 |
| **non_metro** | <$40k | 23436 | 36.6 | | -0.037 | -0.073 | -0.110 | -0.146 | -0.182 |
| **non_metro** | $40k-$80k | 17640 | 63.7 | | -0.053 | -0.106 | -0.159 | -0.212 | -0.265 |
| **non_metro** | >$80k | 12783 | 81.2 | | -0.069 | -0.139 | -0.208 | -0.277 | -0.346 |
| **DevelopmentType** | | | | | | | | | |
| **metro** | Employment | 12117 | 46.4 | | -0.041 | -0.082 | -0.122 | -0.163 | -0.203 |
| **metro** | Low Density/Rural | 6506 | 54.8 | | -0.024 | -0.049 | -0.073 | -0.097 | -0.122 |
| **metro** | Mixed | 3770 | 41.2 | | -0.077 | -0.155 | -0.232 | -0.309 | -0.385 |
| **metro** | Mixed High | 931 | 31.4 | | -0.137 | -0.271 | -0.441 | -0.531 | -0.695 |
| **metro** | Residential | 42829 | 45.7 | | -0.074 | -0.149 | -0.224 | -0.294 | -0.364 |
| **metro** | TOD | 516 | 27.5 | | -0.167 | -0.279 | -0.389 | -0.498 | -0.606 |
| **non_metro** | Employment | 10073 | 51.5 | | -0.058 | -0.116 | -0.174 | -0.231 | -0.289 |
| **non_metro** | Low Density/Rural | 32352 | 58.9 | | -0.019 | -0.038 | -0.058 | -0.077 | -0.096 |
| **non_metro** | Mixed | 160 | 42.3 | | -0.185 | -0.368 | -0.549 | -0.730 | -0.908 |
| **non_metro** | Mixed High | 8 | 27.1 | | -0.336 | -0.665 | -0.987 | -1.302 | -1.611 |
| **non_metro** | Residential | 11261 | 52.2 | | -0.128 | -0.256 | -0.383 | -0.510 | -0.637 |
| **non_metro** | TOD | 5 | 23.8 | | -0.324 | -0.644 | -0.959 | -1.271 | -1.577 |


metro
non_metro
Average AADVMT
54
51
48
45
0
10
20
30
40
50
% increase to D1B
overall

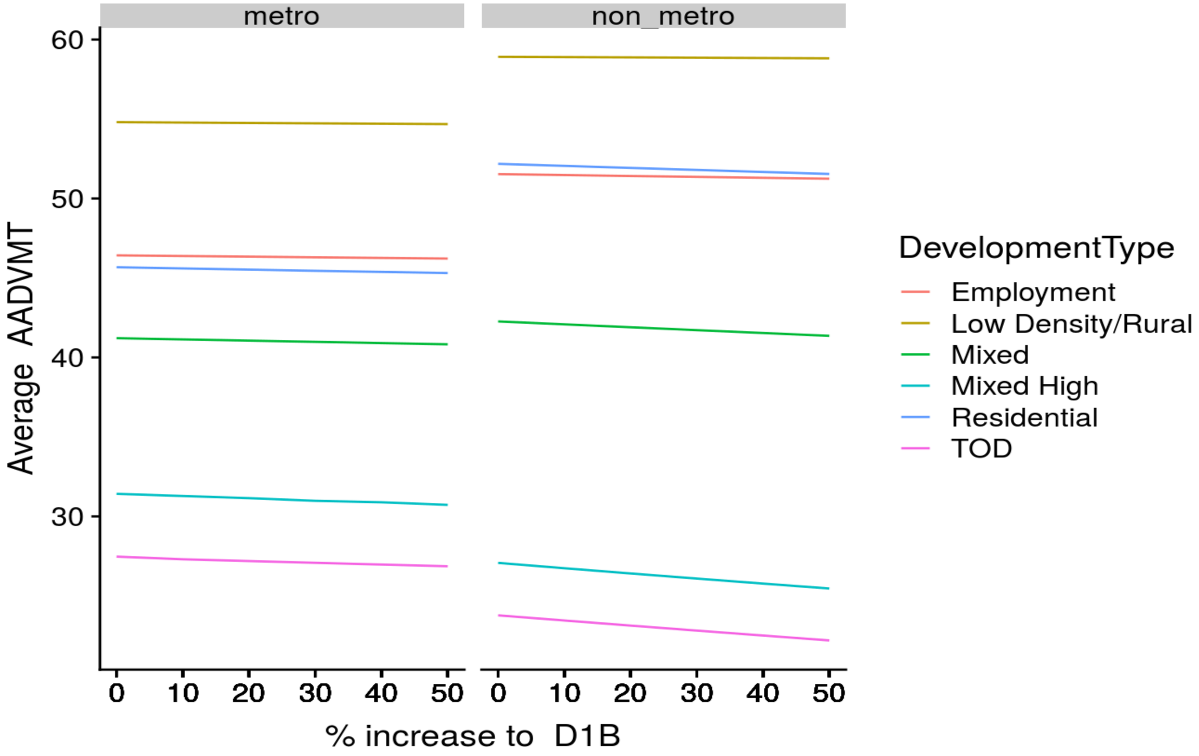
(a)


metro
non_metro
Average AADVMT
50
40
30
0
10
20
30
40
50
% increase to D1B
population_per_sqm
<1k
1k-5k
5k-10k
>10k

(b)



(c)



(d)

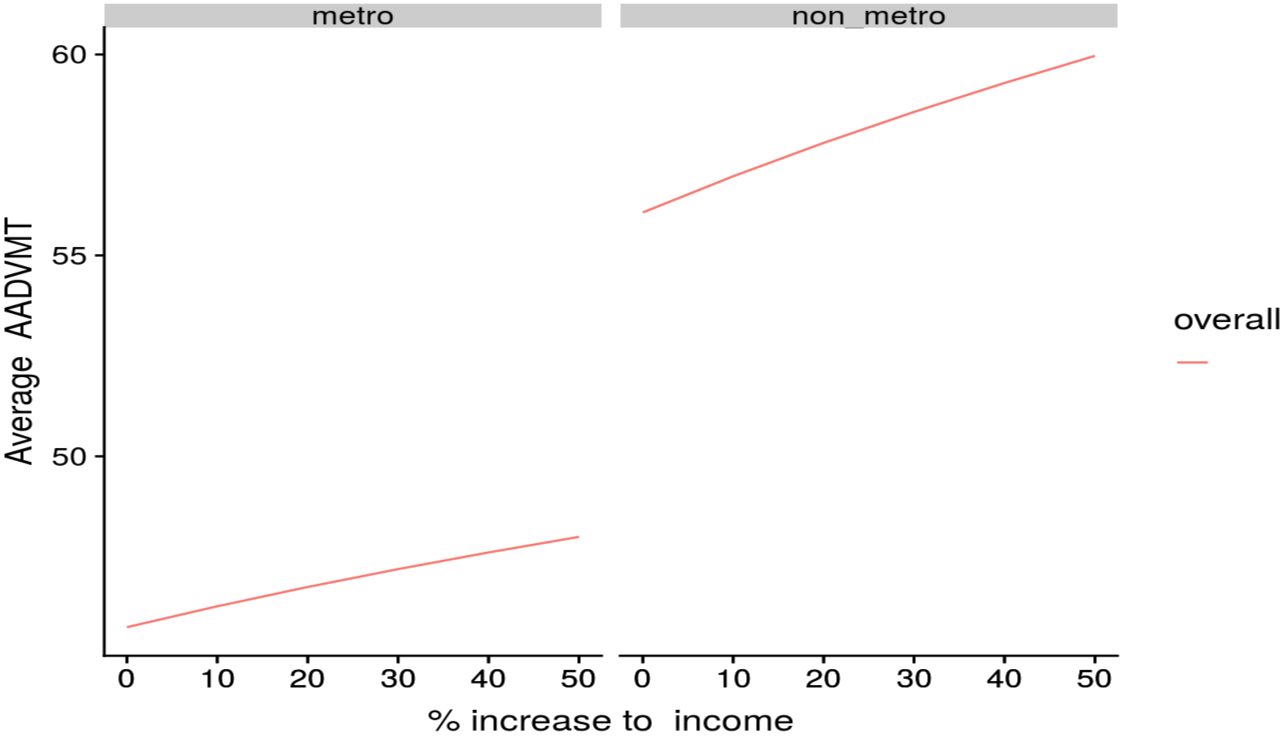
**Figure 4.1 Elasticities of AADVMT with respect to D1B: overall (a); segmented by density (b), income (c) and development type (d).**

#### *4.2.1.2 Household Income Sensitivity*

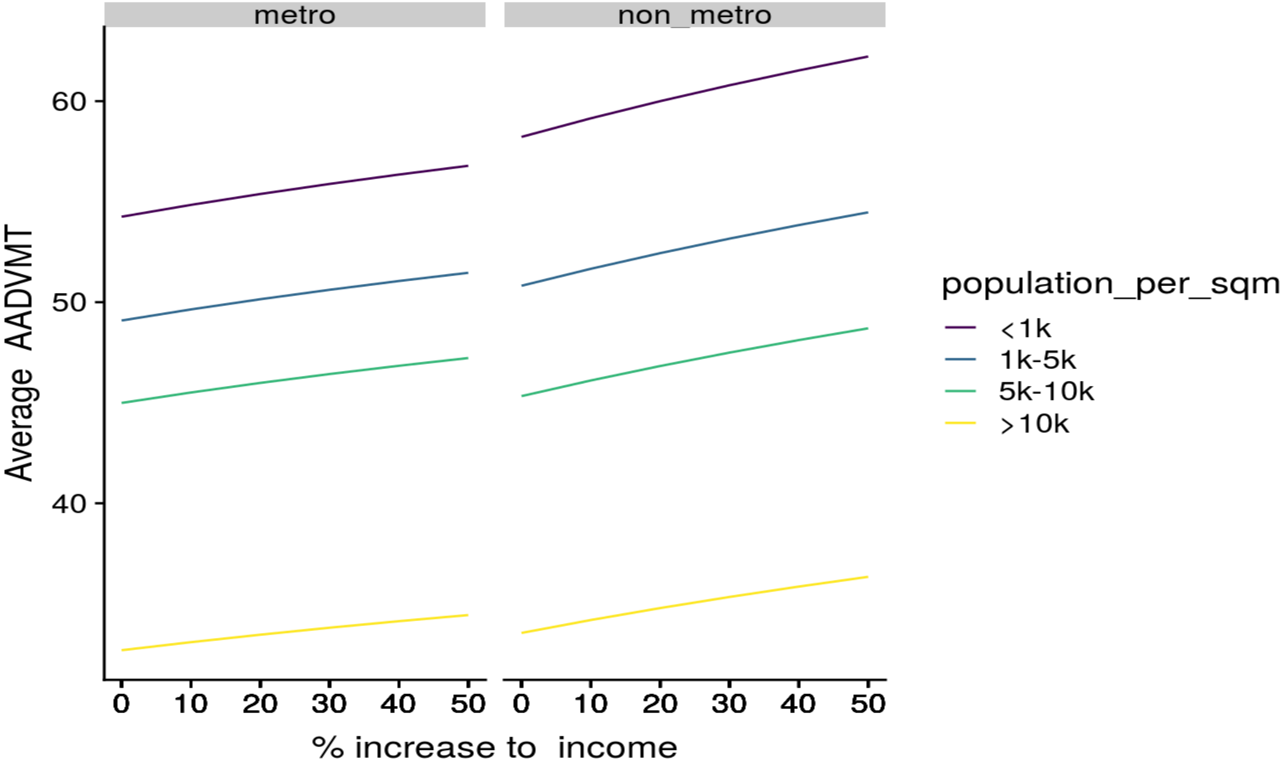
As expected, household income has a positive elasticities to AADVMT (Table 4.2 and Figure 4.2). The elasticities to income are mostly stable across segments.

**Table 4.2 Elasticities of AADVMT with Respect to Household Income**

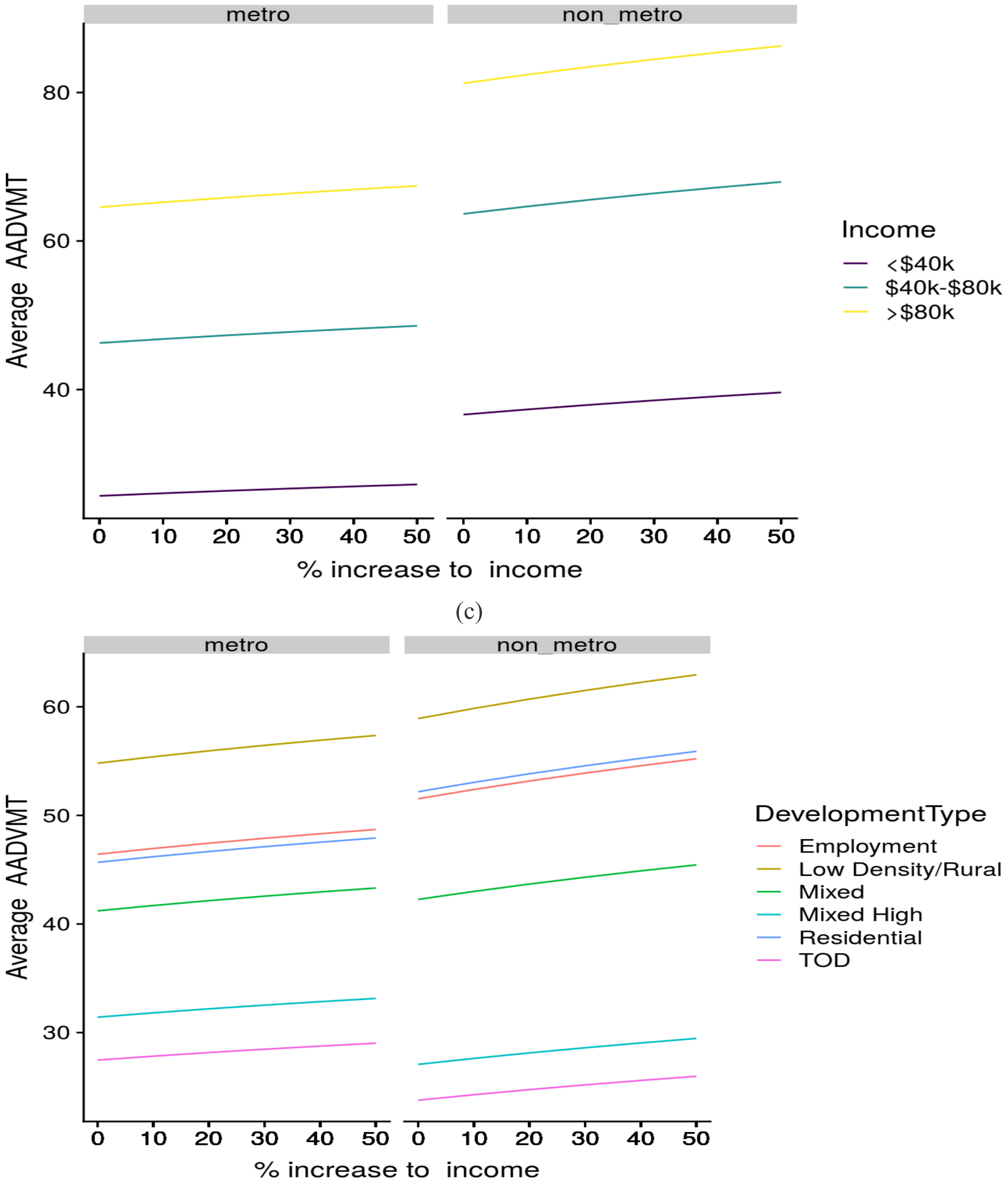
| | | | | | **Δ AADVMT wrt Δ income** | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **metro** | **Category** | **n** | **AADVMT** | | **+10%** | **+20%** | **+30%** | **+40%** | **+50%** |
| **Overall** | | | | | | | | | |
| **metro** | | 66669 | 45.7 | | 0.521 | 1.000 | 1.445 | 1.860 | 2.250 |
| **non_metro** | | 53859 | 56.1 | | 0.901 | 1.731 | 2.502 | 3.220 | 3.900 |
| **population_per_sqm** | | | | | | | | | |
| **metro** | <1k | 6700 | 54.3 | | 0.589 | 1.130 | 1.631 | 2.100 | 2.530 |
| **metro** | 1k-5k | 36154 | 49.1 | | 0.552 | 1.059 | 1.528 | 1.960 | 2.370 |
| **metro** | 5k-10k | 16752 | 45.0 | | 0.519 | 0.996 | 1.437 | 1.850 | 2.230 |
| **metro** | >10k | 7063 | 32.7 | | 0.399 | 0.770 | 1.119 | 1.440 | 1.750 |
| **non_metro** | <1k | 39696 | 58.2 | | 0.925 | 1.777 | 2.568 | 3.310 | 4.000 |
| **non_metro** | 1k-5k | 12572 | 50.8 | | 0.843 | 1.621 | 2.344 | 3.020 | 3.650 |
| **non_metro** | 5k-10k | 1387 | 45.3 | | 0.779 | 1.497 | 2.164 | 2.790 | 3.370 |
| **non_metro** | >10k | 204 | 33.6 | | 0.643 | 1.237 | 1.790 | 2.310 | 2.790 |
| **Income** | | | | | | | | | |
| **metro** | <$40k | 24391 | 25.7 | | 0.355 | 0.683 | 0.989 | 1.270 | 1.540 |
| **metro** | $40k-$80k | 20864 | 46.3 | | 0.537 | 1.031 | 1.488 | 1.910 | 2.310 |
| **metro** | >$80k | 21414 | 64.6 | | 0.668 | 1.282 | 1.850 | 2.380 | 2.870 |
| **non_metro** | <$40k | 23436 | 36.6 | | 0.687 | 1.322 | 1.912 | 2.460 | 2.980 |
| **non_metro** | $40k-$80k | 17640 | 63.7 | | 0.994 | 1.911 | 2.761 | 3.550 | 4.300 |
| **non_metro** | >$80k | 12783 | 81.2 | | 1.163 | 2.235 | 3.228 | 4.150 | 5.020 |
| **DevelopmentType** | | | | | | | | | |
| **metro** | Employment | 12117 | 46.4 | | 0.529 | 1.016 | 1.466 | 1.890 | 2.280 |
| **metro** | Low Density/Rural | 6506 | 54.8 | | 0.595 | 1.141 | 1.647 | 2.120 | 2.560 |
| **metro** | Mixed | 3770 | 41.2 | | 0.487 | 0.936 | 1.351 | 1.740 | 2.100 |
| **metro** | Mixed High | 931 | 31.4 | | 0.400 | 0.769 | 1.110 | 1.430 | 1.730 |
| **metro** | Residential | 42829 | 45.7 | | 0.519 | 0.998 | 1.443 | 1.860 | 2.240 |
| **metro** | TOD | 516 | 27.5 | | 0.361 | 0.693 | 1.001 | 1.290 | 1.560 |
| **non_metro** | Employment | 10073 | 51.5 | | 0.850 | 1.634 | 2.362 | 3.040 | 3.680 |
| **non_metro** | Low Density/Rural | 32352 | 58.9 | | 0.932 | 1.792 | 2.589 | 3.330 | 4.030 |
| **non_metro** | Mixed | 160 | 42.3 | | 0.733 | 1.410 | 2.038 | 2.630 | 3.180 |
| **non_metro** | Mixed High | 8 | 27.1 | | 0.549 | 1.057 | 1.530 | 1.970 | 2.390 |
| **non_metro** | Residential | 11261 | 52.2 | | 0.859 | 1.651 | 2.387 | 3.070 | 3.720 |
| **non_metro** | TOD | 5 | 23.8 | | 0.507 | 0.975 | 1.412 | 1.820 | 2.210 |


metro
non_metro
60
55
50
Average AADVMT
0
10
20
30
40
50
0
10
20
30
40
50
% increase to income
overall

(a)


metro
non_metro
60
50
40
Average AADVMT
0
10
20
30
40
50
0
10
20
30
40
50
% increase to income
population_per_sqm
<1k
1k-5k
5k-10k
>10k

(b)



(c)

(d)

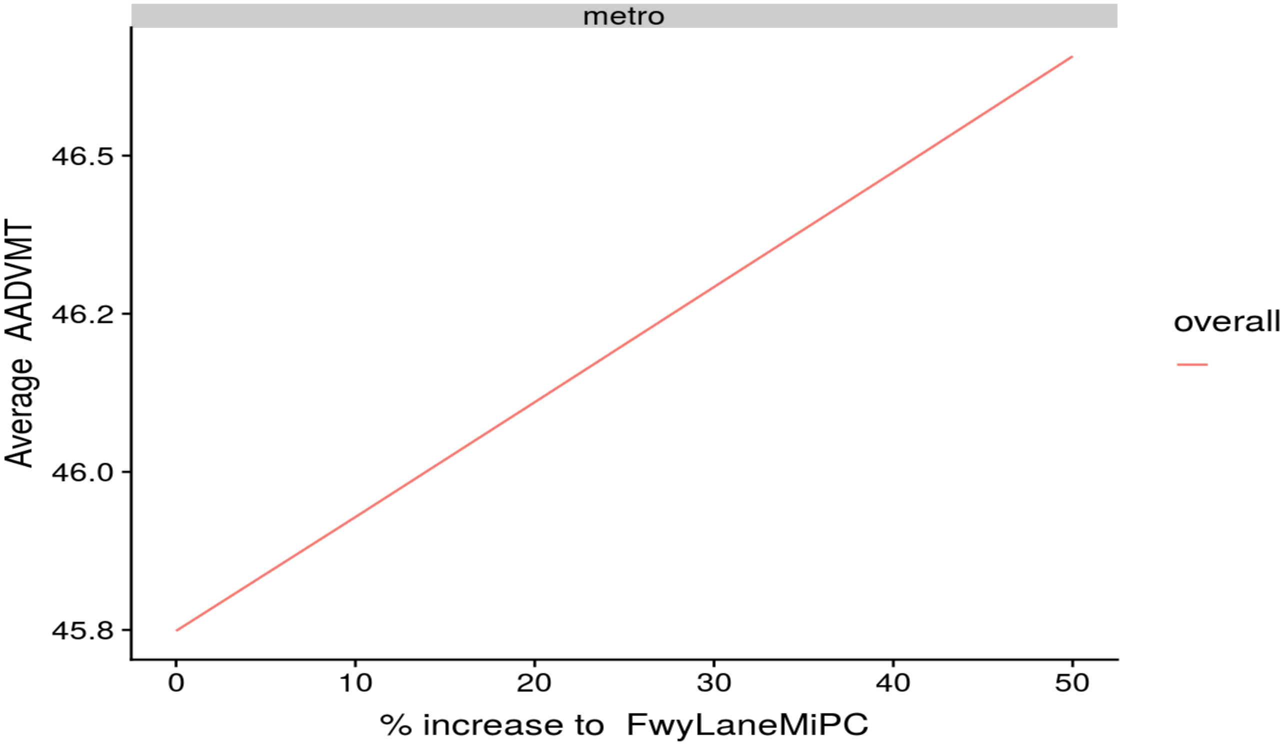
**Figure 4.2 Elasticities of AADVMT with respect to household income: overall (a), segmented by density (b), income (c) and development type (d)**

### *4.2.1.3 Freeway Supply Sensitivity*

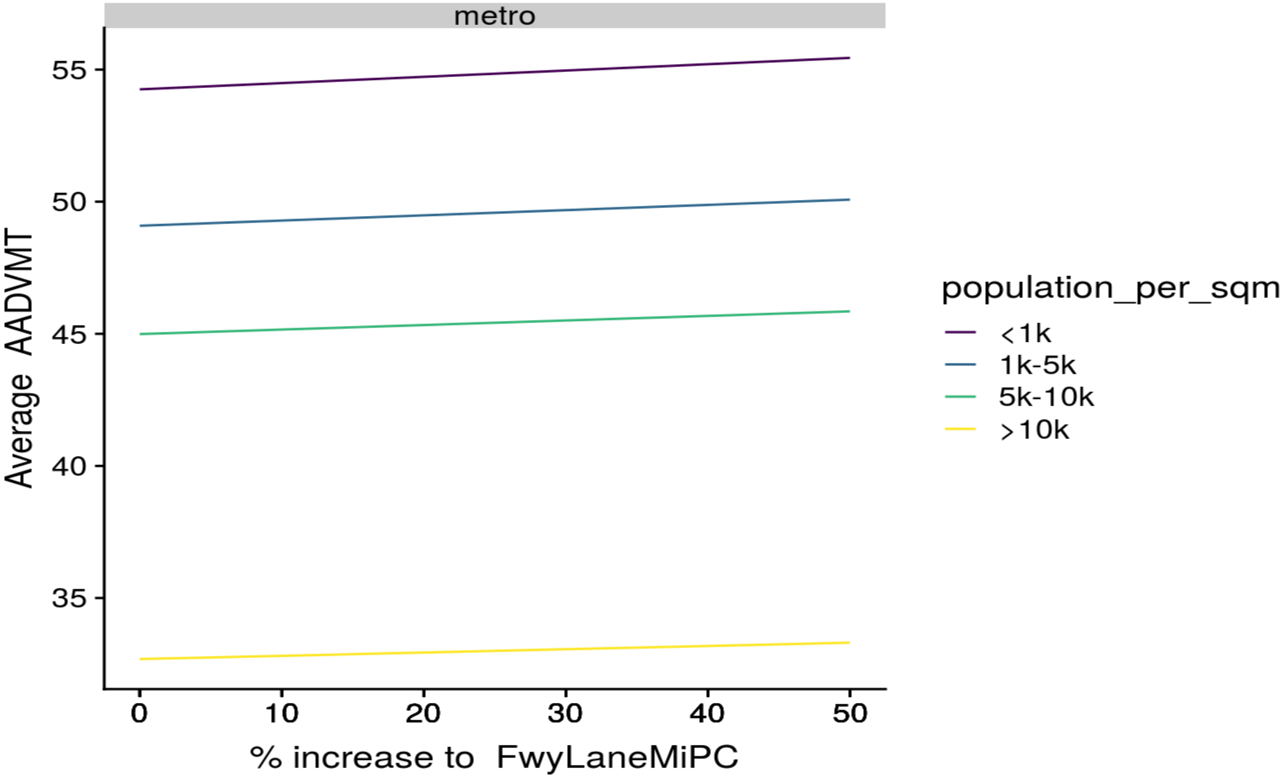
Also, corroborating previous research and Brian's finding, the elasticities to freeway supply is positive but small (Table 4.3 and Figure 4.3), mostly because most places in the US already have good mobility by vehicle, additional freeways lead households to drive slightly more miles.

**Table 4.3 Elasticities of AADVMT with Respect to Freeway Lane Miles per Capita**

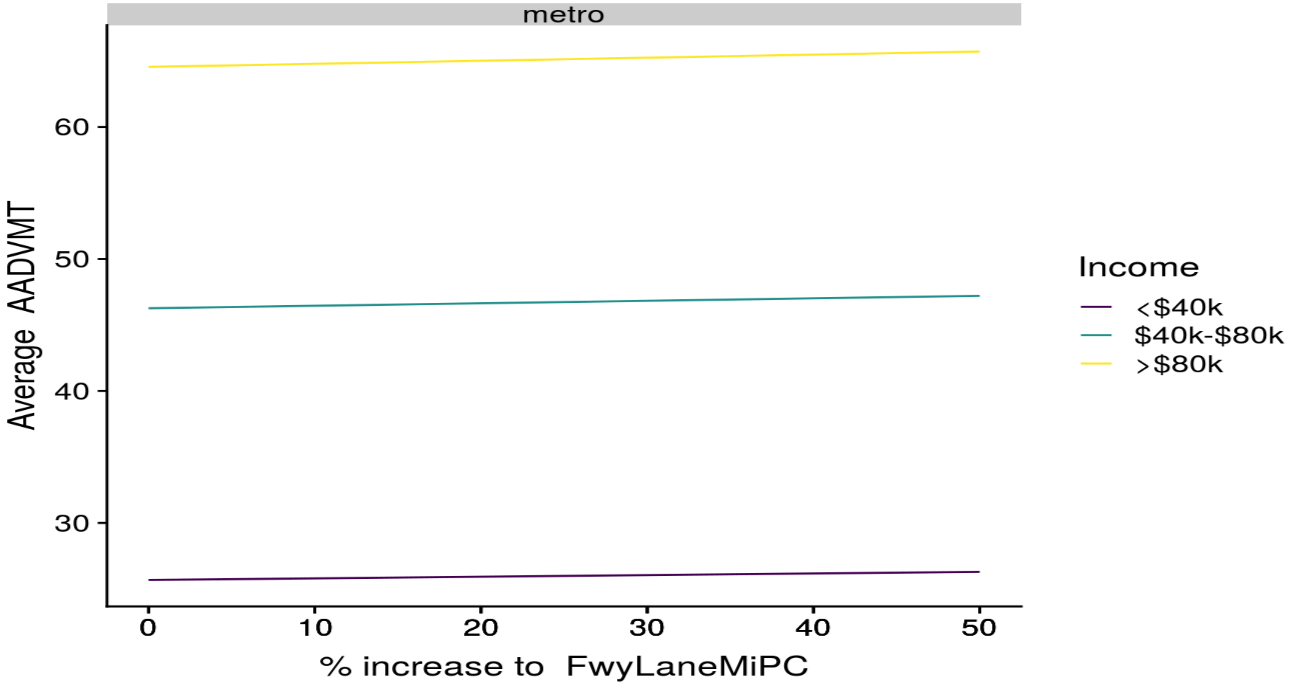
| | | | | | **Δ AADVMT wrt Δ FwyLaneMiPC** | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **metro** | **Category** | **n** | **AADVMT** | | **+10%** | **+20%** | **+30%** | **+40%** | **+50%** |
| **Overall** | | | | | | | | | |
| **metro** | | 66669 | 45.7 | | 0.180 | 0.362 | 0.544 | 0.725 | 0.909 |
| **population_per_sqm** | | | | | | | | | |
| **metro** | <1k | 6700 | 54.3 | | 0.237 | 0.474 | 0.712 | 0.952 | 1.192 |
| **metro** | 1k-5k | 36154 | 49.1 | | 0.197 | 0.394 | 0.592 | 0.790 | 0.989 |
| **metro** | 5k-10k | 16752 | 45.0 | | 0.171 | 0.343 | 0.515 | 0.688 | 0.861 |
| **metro** | >10k | 7063 | 32.7 | | 0.120 | 0.246 | 0.372 | 0.493 | 0.619 |
| **Income** | | | | | | | | | |
| **metro** | <$40k | 24391 | 25.7 | | 0.122 | 0.245 | 0.370 | 0.493 | 0.618 |
| **metro** | $40k-$80k | 20864 | 46.3 | | 0.187 | 0.375 | 0.563 | 0.752 | 0.942 |
| **metro** | >$80k | 21414 | 64.6 | | 0.231 | 0.463 | 0.695 | 0.928 | 1.162 |
| **DevelopmentType** | | | | | | | | | |
| **metro** | Employment | 12117 | 46.4 | | 0.193 | 0.386 | 0.580 | 0.775 | 0.970 |
| **metro** | Low Density/Rural | 6506 | 54.8 | | 0.221 | 0.443 | 0.666 | 0.890 | 1.114 |
| **metro** | Mixed | 3770 | 41.2 | | 0.160 | 0.320 | 0.480 | 0.641 | 0.803 |
| **metro** | Mixed High | 931 | 31.4 | | 0.124 | 0.249 | 0.374 | 0.500 | 0.625 |
| **metro** | Residential | 42829 | 45.7 | | 0.177 | 0.356 | 0.535 | 0.714 | 0.894 |
| **metro** | TOD | 516 | 27.5 | | 0.115 | 0.230 | 0.345 | 0.461 | 0.577 |


metro
46.5
46.2
46.0
45.8
Average AADVMT
0
10
20
30
40
50
% increase to FwyLaneMiPC
overall

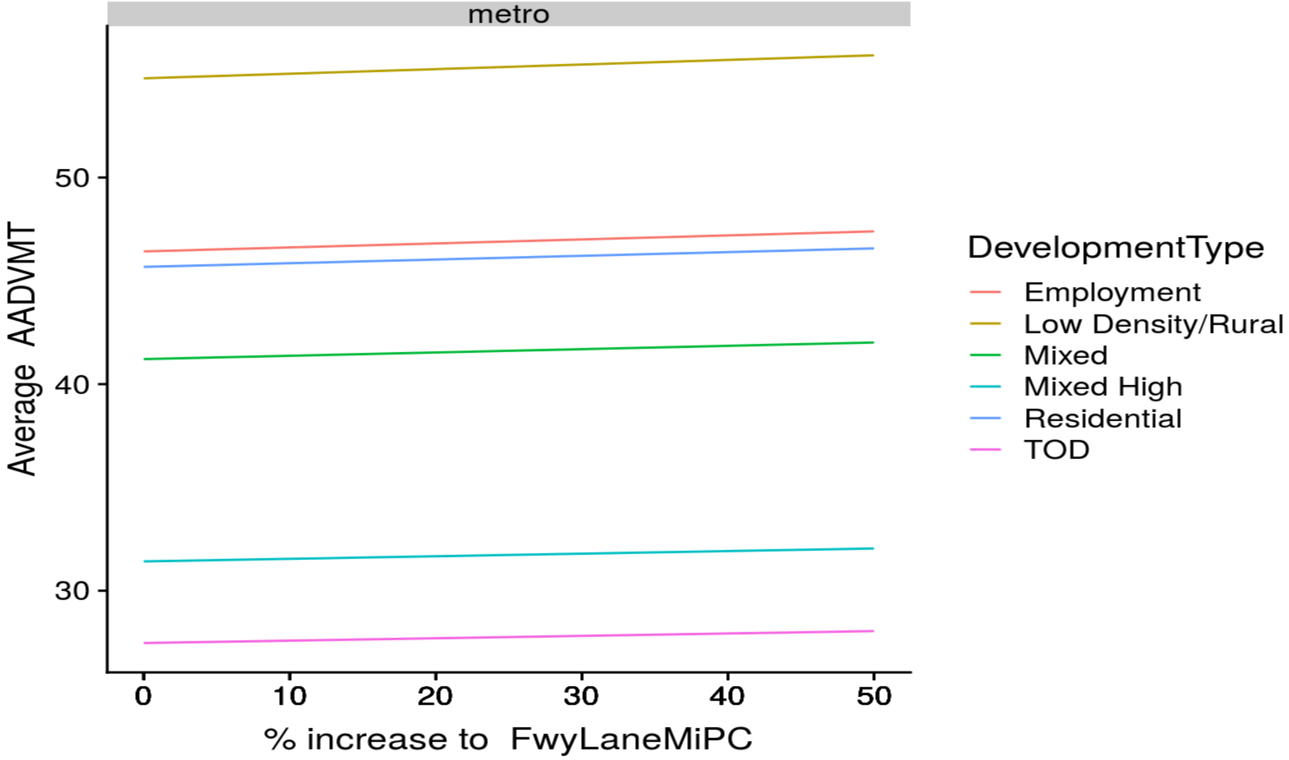
(a)


metro
55
50
45
40
35
Average AADVMT
0
10
20
30
40
50
% increase to FwyLaneMiPC
population_per_sqm
<1k
1k-5k
5k-10k
>10k

(b)



(c)



(d)

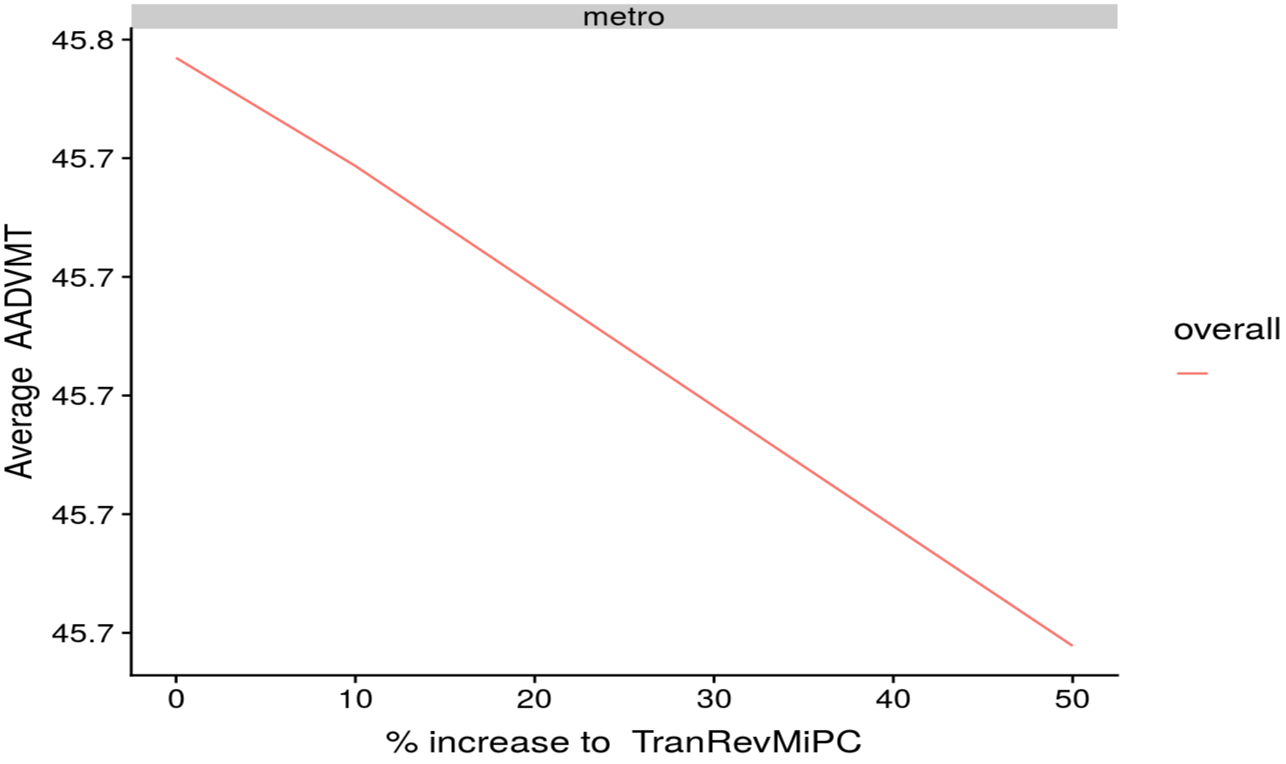
**Figure 4.3 Elasticities of AADVMT with respect to freeway lane miles per capita: overall (a), segmented by density (b), income (c) and development type (d)**

### *4.2.1.4 Transit Supply Sensitivity*

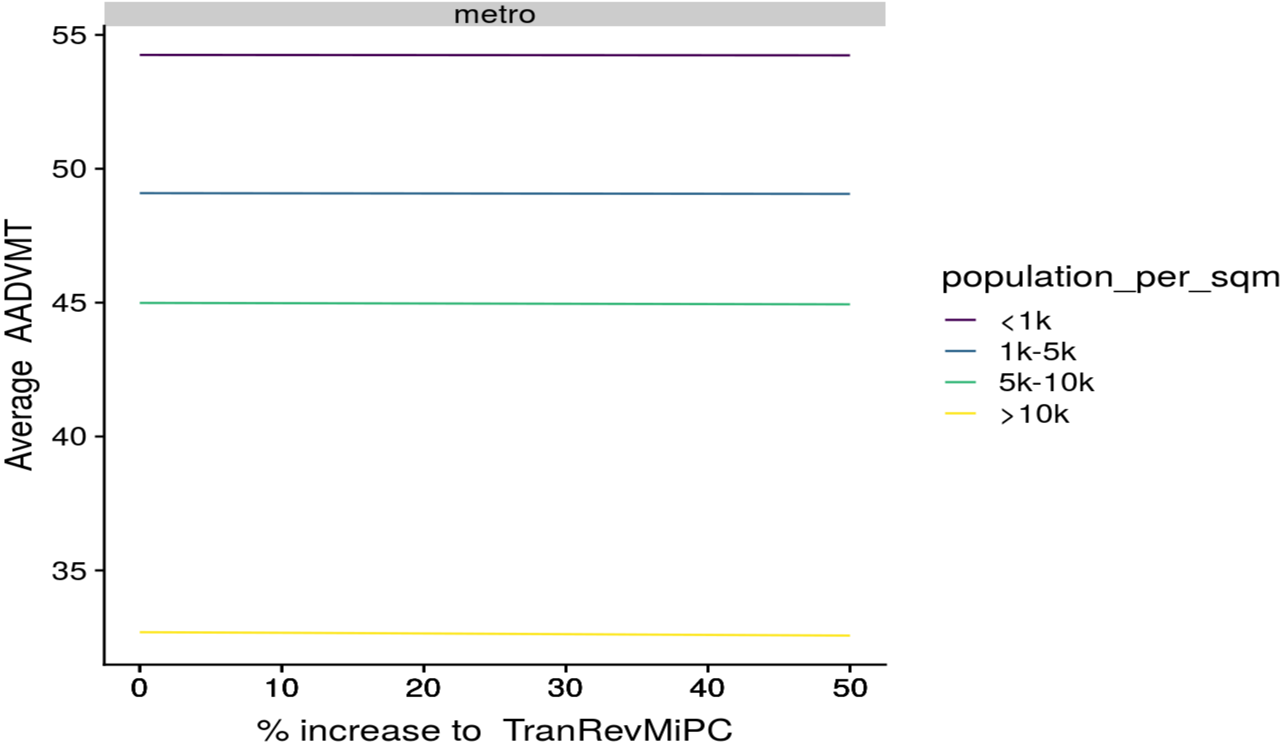
As expected, transit supply (transit revenue miles per capita) has negative elasticities to AADVMT (Table 4.4 and Figure 4.4), which are in line with Brian's numbers. And elasticities are larger for dense areas and for TODs.

**Table 4.4 Elasticities of AADVMT with Respect to Transit Revenue Miles per Capita**

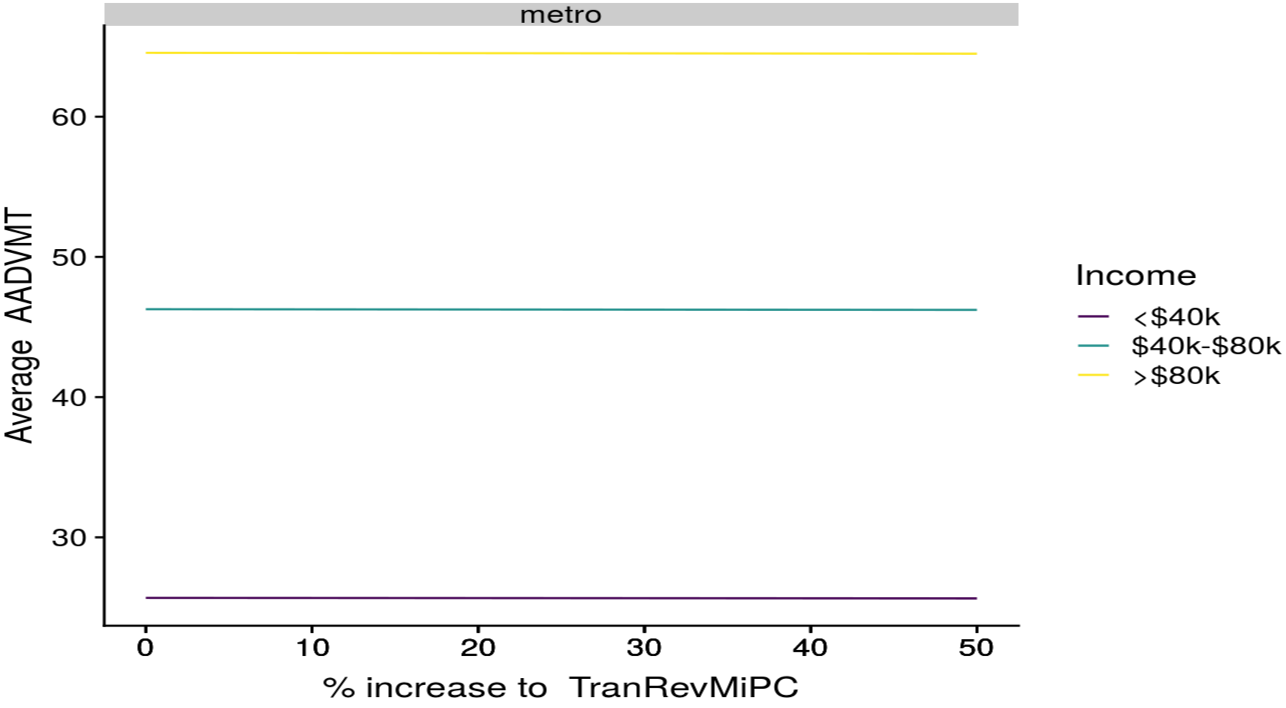
| | | | | | **Δ AADVMT wrt Δ TranRevMiPC** | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **metro** | **Category** | **n** | **AADVMT** | | **+10%** | **+20%** | **+30%** | **+40%** | **+50%** |
| **Overall** | | | | | | | | | |
| **metro** | | 66669 | 45.7 | | -0.009 | -0.019 | -0.029 | -0.039 | -0.050 |
| **population_per_sqm** | | | | | | | | | |
| **metro** | <1k | 6700 | 54.3 | | -0.003 | -0.006 | -0.009 | -0.012 | -0.015 |
| **metro** | 1k-5k | 36154 | 49.1 | | -0.006 | -0.011 | -0.017 | -0.023 | -0.029 |
| **metro** | 5k-10k | 16752 | 45.0 | | -0.011 | -0.021 | -0.032 | -0.042 | -0.053 |
| **metro** | >10k | 7063 | 32.7 | | -0.022 | -0.048 | -0.075 | -0.101 | -0.127 |
| **Income** | | | | | | | | | |
| **metro** | <$40k | 24391 | 25.7 | | -0.006 | -0.014 | -0.022 | -0.029 | -0.037 |
| **metro** | $40k-$80k | 20864 | 46.3 | | -0.010 | -0.019 | -0.029 | -0.039 | -0.049 |
| **metro** | >$80k | 21414 | 64.6 | | -0.013 | -0.025 | -0.038 | -0.051 | -0.063 |
| **DevelopmentType** | | | | | | | | | |
| **metro** | Employment | 12117 | 46.4 | | -0.009 | -0.018 | -0.026 | -0.035 | -0.044 |
| **metro** | Low Density/Rural | 6506 | 54.8 | | -0.001 | -0.003 | -0.004 | -0.005 | -0.007 |
| **metro** | Mixed | 3770 | 41.2 | | -0.021 | -0.043 | -0.064 | -0.085 | -0.106 |
| **metro** | Mixed High | 931 | 31.4 | | -0.019 | -0.038 | -0.056 | -0.075 | -0.094 |
| **metro** | Residential | 42829 | 45.7 | | -0.007 | -0.016 | -0.024 | -0.033 | -0.042 |
| **metro** | TOD | 516 | 27.5 | | -0.101 | -0.201 | -0.301 | -0.400 | -0.499 |


metro
45.8
45.7
45.7
45.7
45.7
45.7
Average AADVMT
0
10
20
30
40
50
% increase to TranRevMiPC
overall

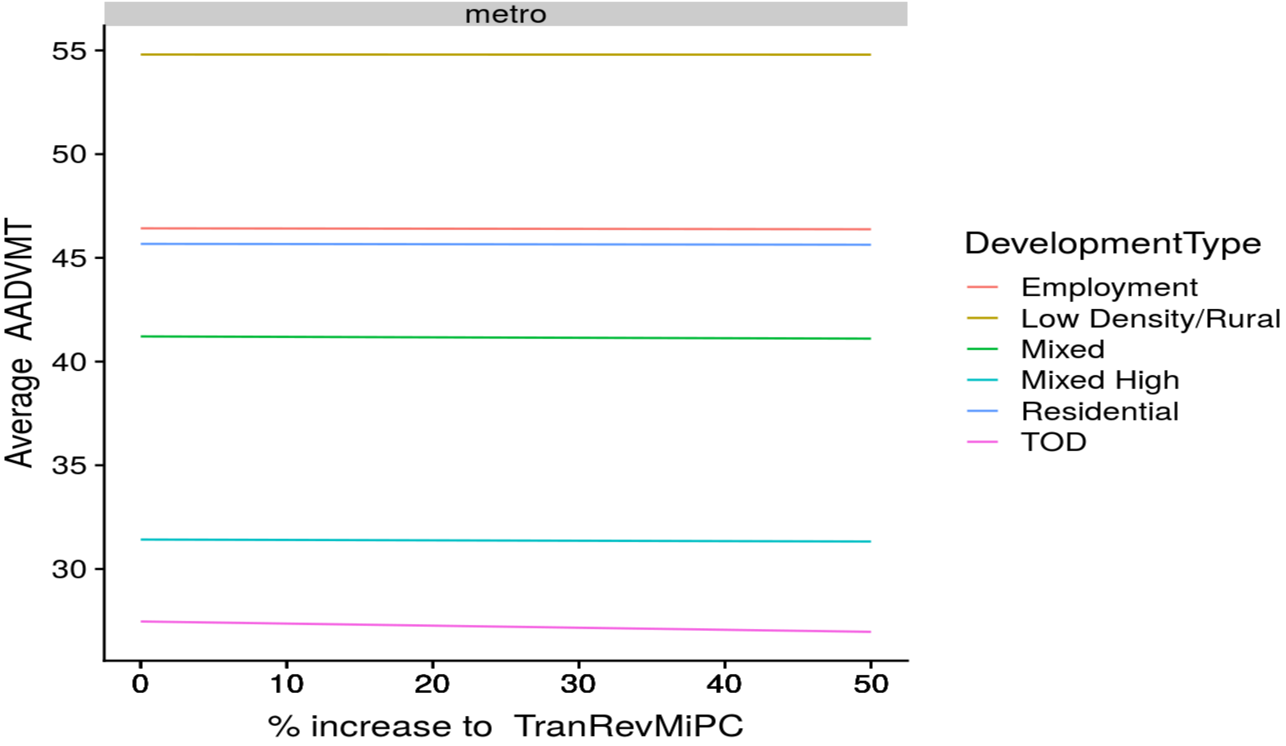
(a)


metro
55
50
45
40
35
Average AADVMT
0
10
20
30
40
50
% increase to TranRevMiPC
population_per_sqm
<1k
1k-5k
5k-10k
>10k

(b)



(c)



(d)

**Figure 4.4 Elasticities of AADVMT with respect to transit revenue miles per capita: overall (a), segmented by density (b), income (c) and development type (d)**

### 4.2.2 Bike PMT

The specification for the Bike PMT model is available in Chapter 3 Bike PMT Model Specification.

#### *4.2.2.1 Population Density (D1B) Sensitivity*

The elasticity estimates of bike person miles traveled per household with respect to population density (D1B) is negative due to the negative D1B coefficient in the model specification. Alternative model specifications have been tested with other density variables (D1C - job density, D1D - activity density) and interactions with D2 variables, the negative coefficient has been persistent.

The elasticities are the largest for the densest (>10,000 persons/sq mile) non-metro areas, with density increases 50%, the bike PMT more than doubled for households living in these areas.

**Table 4.5 Elasticities of Bike PMT with Respect to D1B**

| | | | | | **Δ BikePMT wrt Δ D1B** | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **metro** | **Category** | **n** | **BikePMT** | | **+10%** | **+20%** | **+30%** | **+40%** | **+50%** |
| **Overall** | | | | | | | | | |
| **metro** | | 66669 | 0.1896 | | -0.002 | -0.004 | -0.005 | -0.007 | -0.008 |
| **non_metro** | | 53859 | 0.1623 | | 0.013 | 0.038 | 0.085 | 0.169 | 0.317 |
| **population_per_sqm** | | | | | | | | | |
| **metro** | <1k | 6700 | 0.1670 | | 0.000 | 0.000 | -0.001 | -0.001 | -0.001 |
| **metro** | 1k-5k | 36154 | 0.1784 | | -0.001 | -0.002 | -0.002 | -0.003 | -0.004 |
| **metro** | 5k-10k | 16752 | 0.1968 | | -0.002 | -0.003 | -0.005 | -0.007 | -0.008 |
| **metro** | >10k | 7063 | 0.2287 | | -0.007 | -0.013 | -0.019 | -0.024 | -0.030 |
| **non_metro** | <1k | 39696 | 0.1409 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **non_metro** | 1k-5k | 12572 | 0.1714 | | 0.001 | 0.002 | 0.003 | 0.004 | 0.005 |
| **non_metro** | 5k-10k | 1387 | 0.2385 | | 0.006 | 0.012 | 0.018 | 0.025 | 0.032 |
| **non_metro** | >10k | 204 | 3.6614 | | 3.748 | 11.042 | 24.660 | 49.248 | 92.599 |
| **Income** | | | | | | | | | |
| **metro** | <$40k | 24391 | 0.1198 | | -0.001 | -0.002 | -0.003 | -0.005 | -0.006 |
| **metro** | $40k-$80k | 20864 | 0.1720 | | -0.001 | -0.003 | -0.004 | -0.005 | -0.007 |
| **metro** | >$80k | 21414 | 0.2605 | | -0.003 | -0.005 | -0.008 | -0.010 | -0.012 |
| **non_metro** | <$40k | 23436 | 0.1647 | | 0.031 | 0.091 | 0.204 | 0.407 | 0.764 |
| **non_metro** | $40k-$80k | 17640 | 0.1555 | | 0.001 | 0.001 | 0.002 | 0.003 | 0.004 |
| **non_metro** | >$80k | 12783 | 0.1674 | | 0.001 | 0.001 | 0.002 | 0.003 | 0.003 |
| **DevelopmentType** | | | | | | | | | |
| **metro** | Employment | 12117 | 0.1726 | | -0.001 | -0.003 | -0.004 | -0.005 | -0.007 |
| **metro** | Low Density/Rural | 6506 | 0.1786 | | 0.000 | 0.000 | -0.001 | -0.001 | -0.001 |
| **metro** | Mixed | 3770 | 0.2024 | | -0.003 | -0.006 | -0.009 | -0.011 | -0.014 |
| **metro** | Mixed High | 931 | 0.1819 | | -0.004 | -0.008 | -0.012 | -0.016 | -0.019 |
| **metro** | Residential | 42829 | 0.1852 | | -0.001 | -0.003 | -0.004 | -0.005 | -0.007 |
| **metro** | TOD | 516 | 0.8774 | | -0.044 | -0.085 | -0.122 | -0.157 | -0.188 |
| **non_metro** | Employment | 10073 | 0.1575 | | 0.000 | 0.000 | -0.001 | -0.001 | -0.001 |
| **non_metro** | Low Density/Rural | 32352 | 0.1592 | | 0.021 | 0.062 | 0.139 | 0.277 | 0.520 |
| **non_metro** | Mixed | 160 | 0.1438 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **non_metro** | Mixed High | 8 | 0.1207 | | 0.000 | 0.001 | 0.001 | 0.002 | 0.002 |
| **non_metro** | Residential | 11261 | 0.1756 | | 0.002 | 0.004 | 0.007 | 0.009 | 0.012 |
| **non_metro** | TOD | 5 | 0.0958 | | 0.000 | -0.001 | -0.001 | -0.001 | -0.002 |

#### *4.2.2.2 Household AADVMT Sensitivity*

To capture the relationship between driving and usage of other modes, we include AADVMT in models of non-driving modes. Bike PMT consistently has a negative elasticity to AADVMT with relatively little variations across segments.

**Table 4.6 Elasticities of Bike PMT with Respect to AADVMT**

| | | | | | **Δ BikePMT wrt Δ AADVMT** | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **metro** | **Category** | **n** | **BikePMT** | | **+10%** | **+20%** | **+30%** | **+40%** | **+50%** |
| **Overall** | | | | | | | | | |
| **metro** | | 66669 | 0.1896 | | -0.001 | -0.002 | -0.003 | -0.004 | -0.005 |
| **non_metro** | | 53859 | 0.1623 | | -0.002 | -0.004 | -0.007 | -0.009 | -0.011 |
| **population_per_sqm** | | | | | | | | | |
| **metro** | <1k | 6700 | 0.1670 | | -0.001 | -0.002 | -0.003 | -0.004 | -0.006 |
| **metro** | 1k-5k | 36154 | 0.1784 | | -0.001 | -0.002 | -0.003 | -0.004 | -0.005 |
| **metro** | 5k-10k | 16752 | 0.1968 | | -0.001 | -0.002 | -0.003 | -0.004 | -0.005 |
| **metro** | >10k | 7063 | 0.2287 | | -0.001 | -0.002 | -0.003 | -0.004 | -0.005 |
| **non_metro** | <1k | 39696 | 0.1409 | | -0.002 | -0.004 | -0.006 | -0.008 | -0.010 |
| **non_metro** | 1k-5k | 12572 | 0.1714 | | -0.002 | -0.004 | -0.007 | -0.009 | -0.011 |
| **non_metro** | 5k-10k | 1387 | 0.2385 | | -0.003 | -0.006 | -0.009 | -0.011 | -0.014 |
| **non_metro** | >10k | 204 | 3.6614 | | -0.014 | -0.027 | -0.041 | -0.054 | -0.068 |
| **Income** | | | | | | | | | |
| **metro** | <$40k | 24391 | 0.1198 | | 0.000 | -0.001 | -0.001 | -0.002 | -0.002 |
| **metro** | $40k-$80k | 20864 | 0.1720 | | -0.001 | -0.002 | -0.003 | -0.004 | -0.005 |
| **metro** | >$80k | 21414 | 0.2605 | | -0.002 | -0.003 | -0.005 | -0.006 | -0.008 |
| **non_metro** | <$40k | 23436 | 0.1647 | | -0.001 | -0.003 | -0.004 | -0.006 | -0.007 |
| **non_metro** | $40k-$80k | 17640 | 0.1555 | | -0.002 | -0.005 | -0.007 | -0.009 | -0.012 |
| **non_metro** | >$80k | 12783 | 0.1674 | | -0.003 | -0.006 | -0.009 | -0.012 | -0.015 |
| **DevelopmentType** | | | | | | | | | |
| **metro** | Employment | 12117 | 0.1726 | | -0.001 | -0.002 | -0.003 | -0.004 | -0.005 |
| **metro** | Low Density/Rural | 6506 | 0.1786 | | -0.001 | -0.002 | -0.004 | -0.005 | -0.006 |
| **metro** | Mixed | 3770 | 0.2024 | | -0.001 | -0.002 | -0.003 | -0.004 | -0.005 |
| **metro** | Mixed High | 931 | 0.1819 | | -0.001 | -0.002 | -0.002 | -0.003 | -0.004 |
| **metro** | Residential | 42829 | 0.1852 | | -0.001 | -0.002 | -0.003 | -0.004 | -0.005 |
| **metro** | TOD | 516 | 0.8774 | | -0.002 | -0.005 | -0.007 | -0.010 | -0.012 |
| **non_metro** | Employment | 10073 | 0.1575 | | -0.002 | -0.004 | -0.006 | -0.008 | -0.010 |
| **non_metro** | Low Density/Rural | 32352 | 0.1592 | | -0.002 | -0.004 | -0.007 | -0.009 | -0.011 |
| **non_metro** | Mixed | 160 | 0.1438 | | -0.002 | -0.004 | -0.005 | -0.007 | -0.009 |
| **non_metro** | Mixed High | 8 | 0.1207 | | -0.001 | -0.002 | -0.003 | -0.004 | -0.004 |
| **non_metro** | Residential | 11261 | 0.1756 | | -0.002 | -0.005 | -0.007 | -0.009 | -0.011 |
| **non_metro** | TOD | 5 | 0.0958 | | -0.001 | -0.001 | -0.002 | -0.002 | -0.002 |

#### *4.2.2.3 Household Income Sensitivity*

Bike PMT has a small and positive elasticity to household income.

**Table 4.7 Elasticities of Bike PMT with Respect to Household Income**

| | | | | | **Δ BikePMT wrt Δ income** | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **metro** | **Category** | **n** | **BikePMT** | | **+10%** | **+20%** | **+30%** | **+40%** | **+50%** |
| **overall** | | | | | | | | | |
| **metro** | | 66669 | 0.1896 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **non_metro** | | 53859 | 0.1623 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **population_per_sqm** | | | | | | | | | |
| **metro** | <1k | 6700 | 0.1670 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **metro** | 1k-5k | 36154 | 0.1784 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **metro** | 5k-10k | 16752 | 0.1968 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **metro** | >10k | 7063 | 0.2287 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **non_metro** | <1k | 39696 | 0.1409 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **non_metro** | 1k-5k | 12572 | 0.1714 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **non_metro** | 5k-10k | 1387 | 0.2385 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **non_metro** | >10k | 204 | 3.6614 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **Income** | | | | | | | | | |
| **metro** | <$40k | 24391 | 0.1198 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **metro** | $40k-$80k | 20864 | 0.1720 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **metro** | >$80k | 21414 | 0.2605 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **non_metro** | <$40k | 23436 | 0.1647 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **non_metro** | $40k-$80k | 17640 | 0.1555 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **non_metro** | >$80k | 12783 | 0.1674 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **DevelopmentType** | | | | | | | | | |
| **metro** | Employment | 12117 | 0.1726 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **metro** | Low Density/Rural | 6506 | 0.1786 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **metro** | Mixed | 3770 | 0.2024 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **metro** | Mixed High | 931 | 0.1819 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **metro** | Residential | 42829 | 0.1852 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **metro** | TOD | 516 | 0.8774 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **non_metro** | Employment | 10073 | 0.1575 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **non_metro** | Low Density/Rural | 32352 | 0.1592 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **non_metro** | Mixed | 160 | 0.1438 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **non_metro** | Mixed High | 8 | 0.1207 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **non_metro** | Residential | 11261 | 0.1756 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **non_metro** | TOD | 5 | 0.0958 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

#### *4.2.2.4 Freeway Supply Sensitivity*

**Table 4.8 Elasticities of Bike PMT with Respect to Freeway Lane Miles per Capita**

| | | | | | **Δ BikePMT wrt Δ FwyLaneMiPC** | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **metro** | **Category** | **n** | **BikePMT** | | **+10%** | **+20%** | **+30%** | **+40%** | **+50%** |
| **overall** | | | | | | | | | |
| **metro** | | 66669 | 0.190 | | -0.009 | -0.018 | -0.026 | -0.033 | -0.041 |
| **population_per_sqm** | | | | | | | | | |
| **metro** | <1k | 6700 | 0.167 | | -0.009 | -0.017 | -0.024 | -0.031 | -0.038 |
| **metro** | 1k-5k | 36154 | 0.178 | | -0.009 | -0.017 | -0.025 | -0.032 | -0.039 |
| **metro** | 5k-10k | 16752 | 0.197 | | -0.009 | -0.018 | -0.026 | -0.034 | -0.041 |
| **metro** | >10k | 7063 | 0.229 | | -0.010 | -0.020 | -0.030 | -0.039 | -0.047 |
| **Income** | | | | | | | | | |
| **metro** | <$40k | 24391 | 0.120 | | -0.006 | -0.011 | -0.016 | -0.021 | -0.025 |
| **metro** | $40k-$80k | 20864 | 0.172 | | -0.008 | -0.016 | -0.023 | -0.030 | -0.037 |
| **metro** | >$80k | 21414 | 0.261 | | -0.012 | -0.024 | -0.035 | -0.046 | -0.056 |
| **DevelopmentType** | | | | | | | | | |
| **metro** | Employment | 12117 | 0.173 | | -0.008 | -0.016 | -0.024 | -0.031 | -0.038 |
| **metro** | Low Density/Rural | 6506 | 0.179 | | -0.009 | -0.017 | -0.025 | -0.032 | -0.039 |
| **metro** | Mixed | 3770 | 0.202 | | -0.009 | -0.018 | -0.027 | -0.035 | -0.043 |
| **metro** | Mixed High | 931 | 0.182 | | -0.008 | -0.016 | -0.024 | -0.031 | -0.037 |
| **metro** | Residential | 42829 | 0.185 | | -0.009 | -0.017 | -0.025 | -0.033 | -0.040 |
| **metro** | TOD | 516 | 0.877 | | -0.039 | -0.076 | -0.111 | -0.145 | -0.177 |

#### *4.2.2.5 Transit Supply Sensitivity*

**Table 4.9 Elasticities of Bike PMT with Respect to Transit Revenue Miles per Capita**

| | | | | | **Δ BikePMT wrt Δ TranRevMiPC** | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **metro** | **Category** | **n** | **BikePMT** | | **+10%** | **+20%** | **+30%** | **+40%** | **+50%** |
| **overall** | | | | | | | | | |
| **metro** | | 66669 | 0.190 | | 0.005 | 0.015 | 0.032 | 0.066 | 0.130 |
| **population_per_sqm** | | | | | | | | | |
| **metro** | <1k | 6700 | 0.167 | | -0.001 | -0.002 | -0.002 | -0.003 | -0.004 |
| **metro** | 1k-5k | 36154 | 0.178 | | 0.001 | 0.003 | 0.007 | 0.014 | 0.028 |
| **metro** | 5k-10k | 16752 | 0.197 | | 0.001 | 0.002 | 0.003 | 0.005 | 0.008 |
| **metro** | >10k | 7063 | 0.229 | | 0.036 | 0.100 | 0.219 | 0.444 | 0.882 |
| **Income** | | | | | | | | | |
| **metro** | <$40k | 24391 | 0.120 | | 0.003 | 0.008 | 0.016 | 0.029 | 0.053 |
| **metro** | $40k-$80k | 20864 | 0.172 | | 0.001 | 0.002 | 0.005 | 0.008 | 0.013 |
| **metro** | >$80k | 21414 | 0.261 | | 0.011 | 0.031 | 0.070 | 0.144 | 0.291 |
| **DevelopmentType** | | | | | | | | | |
| **metro** | Employment | 12117 | 0.173 | | 0.000 | 0.000 | 0.000 | 0.001 | 0.001 |
| **metro** | Low Density/Rural | 6506 | 0.179 | | -0.001 | -0.002 | -0.003 | -0.005 | -0.006 |
| **metro** | Mixed | 3770 | 0.202 | | 0.004 | 0.008 | 0.013 | 0.020 | 0.027 |
| **metro** | Mixed High | 931 | 0.182 | | 0.002 | 0.004 | 0.006 | 0.008 | 0.010 |
| **metro** | Residential | 42829 | 0.185 | | 0.001 | 0.003 | 0.005 | 0.008 | 0.014 |
| **metro** | TOD | 516 | 0.877 | | 0.517 | 1.483 | 3.330 | 6.920 | 13.977 |

## 4.2.3 Transit PMT

The specification for the Transit PMT model is available in Chapter 3 Transit PMT Model Specification.

### *4.2.3.1 Population Density (D1B) Sensitivity*

**Table 4.10 Elasticities of Transit PMT with Respect to D1B**

|  |  |  |  |  | **Δ TransitPMT wrt Δ D1B** |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|
| **metro** | **Category** | **n** | **TransitPMT** |  | **+10%** | **+20%** | **+30%** | **+40%** | **+50%** |
| **Overall** |  |  |  |  |  |  |  |  |  |
| **metro** |  | 66669 | 1.362 |  | 0.013 | 0.025 | 0.038 | 0.051 | 0.064 |
| **non_metro** |  | 53859 | 1.776 |  | -0.014 | -0.027 | -0.040 | -0.053 | -0.065 |
| **population_per_sqm** |  |  |  |  |  |  |  |  |  |
| **metro** | <1k | 6700 | 1.151 |  | 0.001 | 0.002 | 0.003 | 0.004 | 0.005 |
| **metro** | 1k-5k | 36154 | 1.217 |  | 0.005 | 0.009 | 0.014 | 0.019 | 0.023 |
| **metro** | 5k-10k | 16752 | 1.242 |  | 0.009 | 0.019 | 0.029 | 0.038 | 0.048 |
| **metro** | >10k | 7063 | 2.314 |  | 0.057 | 0.115 | 0.173 | 0.232 | 0.291 |
| **non_metro** | <1k | 39696 | 1.977 |  | -0.006 | -0.012 | -0.017 | -0.023 | -0.029 |
| **non_metro** | 1k-5k | 12572 | 1.266 |  | -0.035 | -0.068 | -0.101 | -0.133 | -0.163 |
| **non_metro** | 5k-10k | 1387 | 0.718 |  | -0.054 | -0.104 | -0.150 | -0.193 | -0.232 |
| **non_metro** | >10k | 204 | 0.185 |  | -0.027 | -0.050 | -0.069 | -0.086 | -0.100 |
| **Income** |  |  |  |  |  |  |  |  |  |
| **metro** | <$40k | 24391 | 0.876 |  | 0.010 | 0.020 | 0.030 | 0.040 | 0.051 |
| **metro** | $40k-$80k | 20864 | 1.237 |  | 0.012 | 0.023 | 0.035 | 0.047 | 0.059 |
| **metro** | >$80k | 21414 | 1.857 |  | 0.016 | 0.031 | 0.047 | 0.062 | 0.078 |
| **non_metro** | <$40k | 23436 | 1.207 |  | -0.009 | -0.018 | -0.026 | -0.035 | -0.043 |
| **non_metro** | $40k-$80k | 17640 | 1.951 |  | -0.014 | -0.029 | -0.042 | -0.055 | -0.068 |
| **non_metro** | >$80k | 12783 | 2.487 |  | -0.021 | -0.040 | -0.060 | -0.079 | -0.097 |
| **DevelopmentType** |  |  |  |  |  |  |  |  |  |
| **metro** | Employment | 12117 | 1.409 |  | 0.009 | 0.019 | 0.029 | 0.039 | 0.049 |
| **metro** | Low Density/Rural | 6506 | 1.159 |  | 0.002 | 0.003 | 0.005 | 0.006 | 0.008 |
| **metro** | Mixed | 3770 | 1.464 |  | 0.019 | 0.039 | 0.059 | 0.080 | 0.100 |
| **metro** | Mixed High | 931 | 2.434 |  | 0.086 | 0.171 | 0.255 | 0.338 | 0.421 |
| **metro** | Residential | 42829 | 1.319 |  | 0.011 | 0.023 | 0.035 | 0.046 | 0.058 |
| **metro** | TOD | 516 | 3.157 |  | 0.087 | 0.174 | 0.262 | 0.350 | 0.440 |
| **non_metro** | Employment | 10073 | 1.565 |  | -0.019 | -0.038 | -0.056 | -0.074 | -0.091 |
| **non_metro** | Low Density/Rural | 32352 | 1.982 |  | -0.006 | -0.013 | -0.019 | -0.025 | -0.031 |
| **non_metro** | Mixed | 160 | 0.641 |  | -0.029 | -0.055 | -0.081 | -0.104 | -0.126 |
| **non_metro** | Mixed High | 8 | 0.272 |  | -0.010 | -0.020 | -0.029 | -0.038 | -0.046 |
| **non_metro** | Residential | 11261 | 1.378 |  | -0.031 | -0.060 | -0.088 | -0.115 | -0.141 |
| **non_metro** | TOD | 5 | 0.171 |  | -0.012 | -0.024 | -0.034 | -0.043 | -0.051 |

#### *4.2.3.2 Household AADVMT Sensitivitiy*

**Table 4.11 Elasticities of Transit PMT with Respect to AADVMT**

| | | | | | **Δ TransitPMT wrt Δ AADVMT** | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **metro** | **Category** | **n** | **TransitPMT** | | **+10%** | **+20%** | **+30%** | **+40%** | **+50%** |
| **Overall** | | | | | | | | | |
| **metro** | | 66669 | 1.362 | | -0.043 | -0.085 | -0.125 | -0.164 | -0.201 |
| **non_metro** | | 53859 | 1.776 | | 0.037 | 0.074 | 0.113 | 0.153 | 0.194 |
| **population_per_sqm** | | | | | | | | | |
| **metro** | <1k | 6700 | 1.151 | | -0.047 | -0.091 | -0.134 | -0.174 | -0.213 |
| **metro** | 1k-5k | 36154 | 1.217 | | -0.043 | -0.085 | -0.125 | -0.163 | -0.200 |
| **metro** | 5k-10k | 16752 | 1.242 | | -0.040 | -0.079 | -0.116 | -0.152 | -0.187 |
| **metro** | >10k | 7063 | 2.314 | | -0.048 | -0.095 | -0.140 | -0.185 | -0.228 |
| **non_metro** | <1k | 39696 | 1.977 | | 0.042 | 0.085 | 0.129 | 0.174 | 0.221 |
| **non_metro** | 1k-5k | 12572 | 1.266 | | 0.024 | 0.048 | 0.073 | 0.099 | 0.126 |
| **non_metro** | 5k-10k | 1387 | 0.718 | | 0.013 | 0.026 | 0.040 | 0.054 | 0.068 |
| **non_metro** | >10k | 204 | 0.185 | | 0.003 | 0.006 | 0.008 | 0.011 | 0.014 |
| **Income** | | | | | | | | | |
| **metro** | <$40k | 24391 | 0.876 | | -0.020 | -0.039 | -0.057 | -0.075 | -0.093 |
| **metro** | $40k-$80k | 20864 | 1.237 | | -0.038 | -0.075 | -0.110 | -0.144 | -0.176 |
| **metro** | >$80k | 21414 | 1.857 | | -0.067 | -0.131 | -0.193 | -0.252 | -0.308 |
| **non_metro** | <$40k | 23436 | 1.207 | | 0.020 | 0.040 | 0.061 | 0.082 | 0.104 |
| **non_metro** | $40k-$80k | 17640 | 1.951 | | 0.040 | 0.082 | 0.124 | 0.168 | 0.212 |
| **non_metro** | >$80k | 12783 | 2.487 | | 0.060 | 0.122 | 0.187 | 0.253 | 0.321 |
| **DevelopmentType** | | | | | | | | | |
| **metro** | Employment | 12117 | 1.409 | | -0.046 | -0.091 | -0.134 | -0.175 | -0.215 |
| **metro** | Low Density/Rural | 6506 | 1.159 | | -0.048 | -0.094 | -0.137 | -0.179 | -0.219 |
| **metro** | Mixed | 3770 | 1.464 | | -0.040 | -0.079 | -0.117 | -0.154 | -0.189 |
| **metro** | Mixed High | 931 | 2.434 | | -0.039 | -0.078 | -0.115 | -0.152 | -0.187 |
| **metro** | Residential | 42829 | 1.319 | | -0.042 | -0.083 | -0.122 | -0.160 | -0.196 |
| **metro** | TOD | 516 | 3.157 | | -0.048 | -0.096 | -0.142 | -0.187 | -0.232 |
| **non_metro** | Employment | 10073 | 1.565 | | 0.031 | 0.062 | 0.094 | 0.128 | 0.162 |
| **non_metro** | Low Density/Rural | 32352 | 1.982 | | 0.042 | 0.086 | 0.131 | 0.177 | 0.224 |
| **non_metro** | Mixed | 160 | 0.641 | | 0.011 | 0.022 | 0.033 | 0.045 | 0.057 |
| **non_metro** | Mixed High | 8 | 0.272 | | 0.003 | 0.006 | 0.009 | 0.012 | 0.015 |
| **non_metro** | Residential | 11261 | 1.378 | | 0.026 | 0.053 | 0.081 | 0.109 | 0.139 |
| **non_metro** | TOD | 5 | 0.171 | | 0.001 | 0.002 | 0.004 | 0.005 | 0.006 |

#### *4.2.3.3 Household Income Sensitivity*

**Table 4.12 Elasticities of Transit PMT with Respect to Household Income**

| | | | | | **Δ TransitPMT wrt Δ income** | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **metro** | **Category** | **n** | **TransitPMT** | | **+10%** | **+20%** | **+30%** | **+40%** | **+50%** |
| **overall** | | | | | | | | | |
| **metro** | | 66669 | 1.362 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **non_metro** | | 53859 | 1.776 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **population_per_sqm** | | | | | | | | | |
| **metro** | <1k | 6700 | 1.151 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **metro** | 1k-5k | 36154 | 1.217 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **metro** | 5k-10k | 16752 | 1.242 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **metro** | >10k | 7063 | 2.314 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **non_metro** | <1k | 39696 | 1.977 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **non_metro** | 1k-5k | 12572 | 1.266 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **non_metro** | 5k-10k | 1387 | 0.718 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **non_metro** | >10k | 204 | 0.185 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **Income** | | | | | | | | | |
| **metro** | <$40k | 24391 | 0.876 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **metro** | $40k-$80k | 20864 | 1.237 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **metro** | >$80k | 21414 | 1.857 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **non_metro** | <$40k | 23436 | 1.207 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **non_metro** | $40k-$80k | 17640 | 1.951 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **non_metro** | >$80k | 12783 | 2.487 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **DevelopmentType** | | | | | | | | | |
| **metro** | Employment | 12117 | 1.409 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **metro** | Low Density/Rural | 6506 | 1.159 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **metro** | Mixed | 3770 | 1.464 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **metro** | Mixed High | 931 | 2.434 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **metro** | Residential | 42829 | 1.319 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **metro** | TOD | 516 | 3.157 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **non_metro** | Employment | 10073 | 1.565 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **non_metro** | Low Density/Rural | 32352 | 1.982 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **non_metro** | Mixed | 160 | 0.641 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **non_metro** | Mixed High | 8 | 0.272 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **non_metro** | Residential | 11261 | 1.378 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **non_metro** | TOD | 5 | 0.171 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

#### *4.2.3.4 Freeway Supply Sensitivity*

**Table 4.13 Elasticities of Transit PMT with Respect to Freeway Lane Miles per Capita**

| | | | | | **Δ TransitPMT wrt Δ FwyLaneMiPC** | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **metro** | **Category** | **n** | **TransitPMT** | | **+10%** | **+20%** | **+30%** | **+40%** | **+50%** |
| **overall** | | | | | | | | | |
| **metro** | | 66669 | 1.362 | | -0.032 | -0.062 | -0.092 | -0.121 | -0.150 |
| **population_per_sqm** | | | | | | | | | |
| **metro** | <1k | 6700 | 1.151 | | -0.030 | -0.059 | -0.086 | -0.114 | -0.140 |
| **metro** | 1k-5k | 36154 | 1.217 | | -0.030 | -0.059 | -0.086 | -0.114 | -0.140 |
| **metro** | 5k-10k | 16752 | 1.242 | | -0.029 | -0.056 | -0.084 | -0.110 | -0.136 |
| **metro** | >10k | 7063 | 2.314 | | -0.047 | -0.092 | -0.137 | -0.181 | -0.224 |
| **Income** | | | | | | | | | |
| **metro** | <$40k | 24391 | 0.876 | | -0.020 | -0.040 | -0.060 | -0.079 | -0.097 |
| **metro** | $40k-$80k | 20864 | 1.237 | | -0.029 | -0.057 | -0.085 | -0.111 | -0.137 |
| **metro** | >$80k | 21414 | 1.857 | | -0.043 | -0.084 | -0.125 | -0.164 | -0.203 |
| **DevelopmentType** | | | | | | | | | |
| **metro** | Employment | 12117 | 1.409 | | -0.033 | -0.066 | -0.098 | -0.128 | -0.158 |
| **metro** | Low Density/Rural | 6506 | 1.159 | | -0.029 | -0.057 | -0.085 | -0.112 | -0.138 |
| **metro** | Mixed | 3770 | 1.464 | | -0.033 | -0.066 | -0.098 | -0.129 | -0.159 |
| **metro** | Mixed High | 931 | 2.434 | | -0.048 | -0.095 | -0.141 | -0.187 | -0.231 |
| **metro** | Residential | 42829 | 1.319 | | -0.030 | -0.060 | -0.089 | -0.117 | -0.144 |
| **metro** | TOD | 516 | 3.157 | | -0.070 | -0.137 | -0.204 | -0.268 | -0.332 |

#### *4.2.3.5 Transit Supply Sensitivity*

**Table 4.14 Elasticities of Transit PMT with Respect to Transit Revenue Miles per Capita**

| | | | | | **Δ TransitPMT wrt Δ TranRevMiPC** | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **metro** | **Category** | **n** | **TransitPMT** | | **+10%** | **+20%** | **+30%** | **+40%** | **+50%** |
| **overall** | | | | | | | | | |
| **metro** | | 66669 | 1.362 | | 0.091 | 0.188 | 0.292 | 0.404 | 0.522 |
| **population_per_sqm** | | | | | | | | | |
| **metro** | <1k | 6700 | 1.151 | | 0.069 | 0.143 | 0.223 | 0.309 | 0.400 |
| **metro** | 1k-5k | 36154 | 1.217 | | 0.070 | 0.145 | 0.225 | 0.311 | 0.401 |
| **metro** | 5k-10k | 16752 | 1.242 | | 0.079 | 0.163 | 0.252 | 0.348 | 0.450 |
| **metro** | >10k | 7063 | 2.314 | | 0.211 | 0.439 | 0.683 | 0.945 | 1.224 |
| **Income** | | | | | | | | | |
| **metro** | <$40k | 24391 | 0.876 | | 0.055 | 0.115 | 0.178 | 0.247 | 0.320 |
| **metro** | $40k-$80k | 20864 | 1.237 | | 0.079 | 0.163 | 0.254 | 0.351 | 0.454 |
| **metro** | >$80k | 21414 | 1.857 | | 0.130 | 0.269 | 0.417 | 0.575 | 0.742 |
| **DevelopmentType** | | | | | | | | | |
| **metro** | Employment | 12117 | 1.409 | | 0.094 | 0.195 | 0.304 | 0.420 | 0.543 |
| **metro** | Low Density/Rural | 6506 | 1.159 | | 0.065 | 0.133 | 0.207 | 0.286 | 0.370 |
| **metro** | Mixed | 3770 | 1.464 | | 0.104 | 0.216 | 0.336 | 0.464 | 0.601 |
| **metro** | Mixed High | 931 | 2.434 | | 0.176 | 0.362 | 0.559 | 0.767 | 0.987 |
| **metro** | Residential | 42829 | 1.319 | | 0.088 | 0.182 | 0.282 | 0.390 | 0.504 |
| **metro** | TOD | 516 | 3.157 | | 0.289 | 0.596 | 0.920 | 1.261 | 1.619 |

### 4.2.4 Walk PMT

The specification for the Walk PMT model is available in Chapter 3 Walk PMT Model Specification.

#### *4.2.4.1 Population Density (D1B) Sensitivity*

**Table 4.15 Elasticities of Walk PMT with Respect to D1B**

| | | | | | **Δ WalkPMT wrt Δ AADVMT** | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **metro** | **Category** | **n** | **WalkPMT** | | **+10%** | **+20%** | **+30%** | **+40%** | **+50%** |
| **overall** | | | | | | | | | |
| **metro** | | 66669 | 0.596 | | -0.003 | -0.006 | -0.009 | -0.013 | -0.016 |
| **non_metro** | | 53859 | 0.397 | | 0.001 | 0.003 | 0.004 | 0.006 | 0.007 |
| **population_per_sqm** | | | | | | | | | |
| **metro** | <1k | 6700 | 0.473 | | -0.004 | -0.008 | -0.011 | -0.015 | -0.019 |
| **metro** | 1k-5k | 36154 | 0.521 | | -0.003 | -0.007 | -0.010 | -0.014 | -0.017 |
| **metro** | 5k-10k | 16752 | 0.626 | | -0.003 | -0.006 | -0.009 | -0.013 | -0.016 |
| **metro** | >10k | 7063 | 0.887 | | -0.002 | -0.003 | -0.005 | -0.007 | -0.009 |
| **non_metro** | <1k | 39696 | 0.387 | | 0.001 | 0.003 | 0.004 | 0.006 | 0.007 |
| **non_metro** | 1k-5k | 12572 | 0.409 | | 0.001 | 0.003 | 0.004 | 0.005 | 0.007 |
| **non_metro** | 5k-10k | 1387 | 0.566 | | 0.002 | 0.004 | 0.006 | 0.008 | 0.011 |
| **non_metro** | >10k | 204 | 0.642 | | 0.002 | 0.003 | 0.005 | 0.007 | 0.009 |
| **Income** | | | | | | | | | |
| **metro** | <$40k | 24391 | 0.491 | | -0.002 | -0.004 | -0.006 | -0.008 | -0.010 |
| **metro** | $40k-$80k | 20864 | 0.567 | | -0.003 | -0.006 | -0.009 | -0.012 | -0.015 |
| **metro** | >$80k | 21414 | 0.705 | | -0.004 | -0.008 | -0.012 | -0.017 | -0.021 |
| **non_metro** | <$40k | 23436 | 0.311 | | 0.001 | 0.001 | 0.002 | 0.003 | 0.004 |
| **non_metro** | $40k-$80k | 17640 | 0.420 | | 0.002 | 0.003 | 0.005 | 0.006 | 0.008 |
| **non_metro** | >$80k | 12783 | 0.512 | | 0.002 | 0.005 | 0.007 | 0.010 | 0.013 |
| **DevelopmentType** | | | | | | | | | |
| **metro** | Employment | 12117 | 0.549 | | -0.003 | -0.006 | -0.010 | -0.013 | -0.016 |
| **metro** | Low Density/Rural | 6506 | 0.499 | | -0.004 | -0.008 | -0.012 | -0.016 | -0.020 |
| **metro** | Mixed | 3770 | 0.663 | | -0.003 | -0.005 | -0.008 | -0.011 | -0.014 |
| **metro** | Mixed High | 931 | 0.972 | | -0.001 | -0.002 | -0.002 | -0.003 | -0.004 |
| **metro** | Residential | 42829 | 0.596 | | -0.003 | -0.006 | -0.010 | -0.013 | -0.016 |
| **metro** | TOD | 516 | 1.248 | | 0.001 | 0.002 | 0.003 | 0.005 | 0.006 |
| **non_metro** | Employment | 10073 | 0.398 | | 0.001 | 0.003 | 0.004 | 0.005 | 0.007 |
| **non_metro** | Low Density/Rural | 32352 | 0.387 | | 0.001 | 0.003 | 0.004 | 0.006 | 0.007 |
| **non_metro** | Mixed | 160 | 0.502 | | 0.002 | 0.004 | 0.006 | 0.008 | 0.010 |
| **non_metro** | Mixed High | 8 | 1.038 | | 0.002 | 0.004 | 0.006 | 0.008 | 0.010 |
| **non_metro** | Residential | 11261 | 0.425 | | 0.001 | 0.003 | 0.004 | 0.006 | 0.007 |
| **non_metro** | TOD | 5 | 1.204 | | 0.002 | 0.003 | 0.005 | 0.007 | 0.009 |

### *4.2.4.2 Household Income Sensitivity*

**Table 4.16 Elasticities of Walk PMT with Respect to Household Income**

|  |  |  |  |  | **Δ WalkPMT wrt Δ income** |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|
| **metro** | **Category** | **n** | **WalkPMT** |  | **+10%** | **+20%** | **+30%** | **+40%** | **+50%** |
| **overall** |  |  |  |  |  |  |  |  |  |
| **metro** |  | 66669 | 0.596 |  | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **non_metro** |  | 53859 | 0.397 |  | 0.006 | 0.011 | 0.016 | 0.021 | 0.025 |
| **population_per_sqm** |  |  |  |  |  |  |  |  |  |
| **metro** | <1k | 6700 | 0.473 |  | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **metro** | 1k-5k | 36154 | 0.521 |  | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **metro** | 5k-10k | 16752 | 0.626 |  | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **metro** | >10k | 7063 | 0.887 |  | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **non_metro** | <1k | 39696 | 0.387 |  | 0.006 | 0.011 | 0.016 | 0.020 | 0.025 |
| **non_metro** | 1k-5k | 12572 | 0.409 |  | 0.006 | 0.011 | 0.016 | 0.021 | 0.025 |
| **non_metro** | 5k-10k | 1387 | 0.566 |  | 0.007 | 0.014 | 0.021 | 0.027 | 0.032 |
| **non_metro** | >10k | 204 | 0.642 |  | 0.008 | 0.016 | 0.023 | 0.029 | 0.035 |
| **Income** |  |  |  |  |  |  |  |  |  |
| **metro** | <$40k | 24391 | 0.491 |  | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **metro** | $40k-$80k | 20864 | 0.567 |  | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **metro** | >$80k | 21414 | 0.705 |  | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **non_metro** | <$40k | 23436 | 0.311 |  | 0.005 | 0.009 | 0.013 | 0.017 | 0.021 |
| **non_metro** | $40k-$80k | 17640 | 0.420 |  | 0.006 | 0.012 | 0.017 | 0.022 | 0.026 |
| **non_metro** | >$80k | 12783 | 0.512 |  | 0.007 | 0.013 | 0.019 | 0.025 | 0.030 |
| **DevelopmentType** |  |  |  |  |  |  |  |  |  |
| **metro** | Employment | 12117 | 0.549 |  | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **metro** | Low Density/Rural | 6506 | 0.499 |  | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **metro** | Mixed | 3770 | 0.663 |  | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **metro** | Mixed High | 931 | 0.972 |  | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **metro** | Residential | 42829 | 0.596 |  | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **metro** | TOD | 516 | 1.248 |  | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **non_metro** | Employment | 10073 | 0.398 |  | 0.006 | 0.011 | 0.016 | 0.021 | 0.025 |
| **non_metro** | Low Density/Rural | 32352 | 0.387 |  | 0.006 | 0.011 | 0.016 | 0.020 | 0.025 |
| **non_metro** | Mixed | 160 | 0.502 |  | 0.007 | 0.013 | 0.019 | 0.025 | 0.030 |
| **non_metro** | Mixed High | 8 | 1.038 |  | 0.011 | 0.022 | 0.031 | 0.040 | 0.049 |
| **non_metro** | Residential | 11261 | 0.425 |  | 0.006 | 0.012 | 0.017 | 0.021 | 0.026 |
| **non_metro** | TOD | 5 | 1.204 |  | 0.010 | 0.018 | 0.026 | 0.034 | 0.041 |

### *4.2.4.3 Freeway Supply Sensitivity*

**Table 4.17 Elasticities of Walk PMT with Respect to Freeway Lane Miles per Capita**

| | | | | | **Δ WalkPMT wrt Δ FwyLaneMiPC** | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **metro** | **Category** | **n** | **WalkPMT** | | **+10%** | **+20%** | **+30%** | **+40%** | **+50%** |
| **overall** | | | | | | | | | |
| **metro** | | 66669 | 0.596 | | -0.003 | -0.005 | -0.008 | -0.011 | -0.013 |
| **population_per_sqm** | | | | | | | | | |
| **metro** | <1k | 6700 | 0.473 | | -0.002 | -0.005 | -0.007 | -0.009 | -0.011 |
| **metro** | 1k-5k | 36154 | 0.521 | | -0.002 | -0.005 | -0.007 | -0.009 | -0.012 |
| **metro** | 5k-10k | 16752 | 0.626 | | -0.003 | -0.006 | -0.008 | -0.011 | -0.014 |
| **metro** | >10k | 7063 | 0.887 | | -0.004 | -0.008 | -0.012 | -0.015 | -0.019 |
| **Income** | | | | | | | | | |
| **metro** | <$40k | 24391 | 0.491 | | -0.002 | -0.004 | -0.006 | -0.008 | -0.010 |
| **metro** | $40k-$80k | 20864 | 0.567 | | -0.003 | -0.005 | -0.007 | -0.010 | -0.012 |
| **metro** | >$80k | 21414 | 0.705 | | -0.003 | -0.007 | -0.010 | -0.013 | -0.016 |
| **DevelopmentType** | | | | | | | | | |
| **metro** | Employment | 12117 | 0.549 | | -0.002 | -0.005 | -0.007 | -0.010 | -0.012 |
| **metro** | Low Density/Rural | 6506 | 0.499 | | -0.002 | -0.005 | -0.007 | -0.009 | -0.011 |
| **metro** | Mixed | 3770 | 0.663 | | -0.003 | -0.006 | -0.008 | -0.011 | -0.014 |
| **metro** | Mixed High | 931 | 0.972 | | -0.004 | -0.008 | -0.012 | -0.017 | -0.021 |
| **metro** | Residential | 42829 | 0.596 | | -0.003 | -0.005 | -0.008 | -0.011 | -0.013 |
| **metro** | TOD | 516 | 1.248 | | -0.006 | -0.012 | -0.017 | -0.023 | -0.029 |

#### *4.2.4.4 Transit Supply Sensitivity*

**Table 4.18 Elasticities of Walk PMT with Respect to Transit Revenue Miles per Capita**

| | | | | | **Δ WalkPMT wrt Δ TranRevMiPC** | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **metro** | **Category** | **n** | **WalkPMT** | | **+10%** | **+20%** | **+30%** | **+40%** | **+50%** |
| **overall** | | | | | | | | | |
| **metro** | | 66669 | 0.596 | | 0.009 | 0.018 | 0.027 | 0.036 | 0.045 |
| **population_per_sqm** | | | | | | | | | |
| **metro** | <1k | 6700 | 0.473 | | 0.007 | 0.013 | 0.020 | 0.027 | 0.034 |
| **metro** | 1k-5k | 36154 | 0.521 | | 0.007 | 0.015 | 0.022 | 0.029 | 0.037 |
| **metro** | 5k-10k | 16752 | 0.626 | | 0.009 | 0.018 | 0.028 | 0.037 | 0.046 |
| **metro** | >10k | 7063 | 0.887 | | 0.015 | 0.031 | 0.046 | 0.062 | 0.077 |
| **Income** | | | | | | | | | |
| **metro** | <$40k | 24391 | 0.491 | | 0.007 | 0.015 | 0.022 | 0.029 | 0.037 |
| **metro** | $40k-$80k | 20864 | 0.567 | | 0.008 | 0.017 | 0.025 | 0.034 | 0.042 |
| **metro** | >$80k | 21414 | 0.705 | | 0.011 | 0.021 | 0.032 | 0.043 | 0.053 |
| **DevelopmentType** | | | | | | | | | |
| **metro** | Employment | 12117 | 0.549 | | 0.008 | 0.017 | 0.025 | 0.034 | 0.042 |
| **metro** | Low Density/Rural | 6506 | 0.499 | | 0.007 | 0.014 | 0.021 | 0.028 | 0.035 |
| **metro** | Mixed | 3770 | 0.663 | | 0.010 | 0.020 | 0.030 | 0.040 | 0.051 |
| **metro** | Mixed High | 931 | 0.972 | | 0.012 | 0.024 | 0.036 | 0.048 | 0.059 |
| **metro** | Residential | 42829 | 0.596 | | 0.009 | 0.018 | 0.027 | 0.036 | 0.045 |
| **metro** | TOD | 516 | 1.248 | | 0.015 | 0.030 | 0.044 | 0.059 | 0.074 |

## 4.3 PHASE II

The models (AADVMT model, trip frequency model and person mile traveled model for bike, walk, and transit) are applied to RVMPO data using the VisionEval framework with RSPM/VisionEval synthesized households and supplemental block group built environment level inputs. Below are the prediction outputs from the new models and RSPM, and the comparison with OHAS (weighted averages).

### 4.3.1 Predictions from the New Models

**Table 4.19 VETravelDemandMM Predictions**

| | | | | Trips | | | | PMT | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Category** | **n** | **AADVMT** | | **Bike Trips** | **Walk Trips** | **Transit Trips** | | **Bike PMT** | **Walk PMT** | **Transit PMT** |
| **Overall** | | | | | | | | | | |
| **RVMPO** | 74045 | 41.800 | | 0.146 | 0.891 | 0.144 | | 0.290 | 0.578 | 0.751 |
| **DevelopmentType** | | | | | | | | | | |
| **Rural** | 6476 | 49.200 | | 0.158 | 0.754 | 0.134 | | 0.294 | 0.513 | 0.816 |
| **Urban** | 67569 | 41.100 | | 0.145 | 0.905 | 0.145 | | 0.290 | 0.584 | 0.745 |
| **Income** | | | | | | | | | | |
| **<$40k** | 31432 | 25.100 | | 0.124 | 0.762 | 0.180 | | 0.167 | 0.482 | 0.676 |
| **$40k-$80k** | 18071 | 43.800 | | 0.149 | 0.907 | 0.125 | | 0.288 | 0.586 | 0.754 |
| **>$80k** | 24542 | 61.800 | | 0.172 | 1.045 | 0.111 | | 0.449 | 0.694 | 0.844 |
| **Population per Square Mile** | | | | | | | | | | |
| **<1k** | 19126 | 42.300 | | 0.143 | 0.710 | 0.133 | | 0.249 | 0.476 | 0.739 |
| **1k-5k** | 35477 | 42.300 | | 0.144 | 0.898 | 0.141 | | 0.294 | 0.579 | 0.753 |
| **5k-10k** | 18211 | 40.700 | | 0.151 | 1.071 | 0.157 | | 0.327 | 0.682 | 0.757 |
| **>10k** | 1231 | 36.900 | | 0.157 | 0.876 | 0.202 | | 0.258 | 0.575 | 0.792 |

### 4.3.2 RSPM Predictions

**Table 4.20 RSPM Predictions**

| | | | | Trips | | |
|---|---|---|---|---|---|---|
| **Category** | **n** | **DVMT** | | **BikeTrips** | **WalkTrips** | **TransitTrips** |
| **Overall** | | | | | | |
| **RVMPO** | 74045 | 52.400 | | 0.092 | 0.690 | 0.037 |
| **DevelopmentType** | | | | | | |
| **Rural** | 6676 | 65.400 | | 0.088 | 0.741 | 0.023 |
| **Urban** | 67369 | 51.200 | | 0.092 | 0.685 | 0.038 |
| **Income** | | | | | | |
| **<$40k** | 31791 | 34.700 | | 0.090 | 0.604 | 0.053 |
| **$40k-$80k** | 17852 | 56.200 | | 0.090 | 0.645 | 0.023 |
| **>$80k** | 24402 | 72.800 | | 0.095 | 0.834 | 0.026 |
| **Population per Square Mile** | | | | | | |
| **<1k** | 19208 | 57.400 | | 0.087 | 0.598 | 0.022 |
| **1k-5k** | 34215 | 54.300 | | 0.093 | 0.704 | 0.035 |
| **5k-10k** | 19384 | 45.900 | | 0.094 | 0.752 | 0.050 |
| **>10k** | 1238 | 29.200 | | 0.103 | 0.751 | 0.108 |

### 4.3.3 OHAS Observations

Those are the weighted average trip and person mile traveled per household by mode from the 2012 Oregon Household Activity Survey for RVMPO

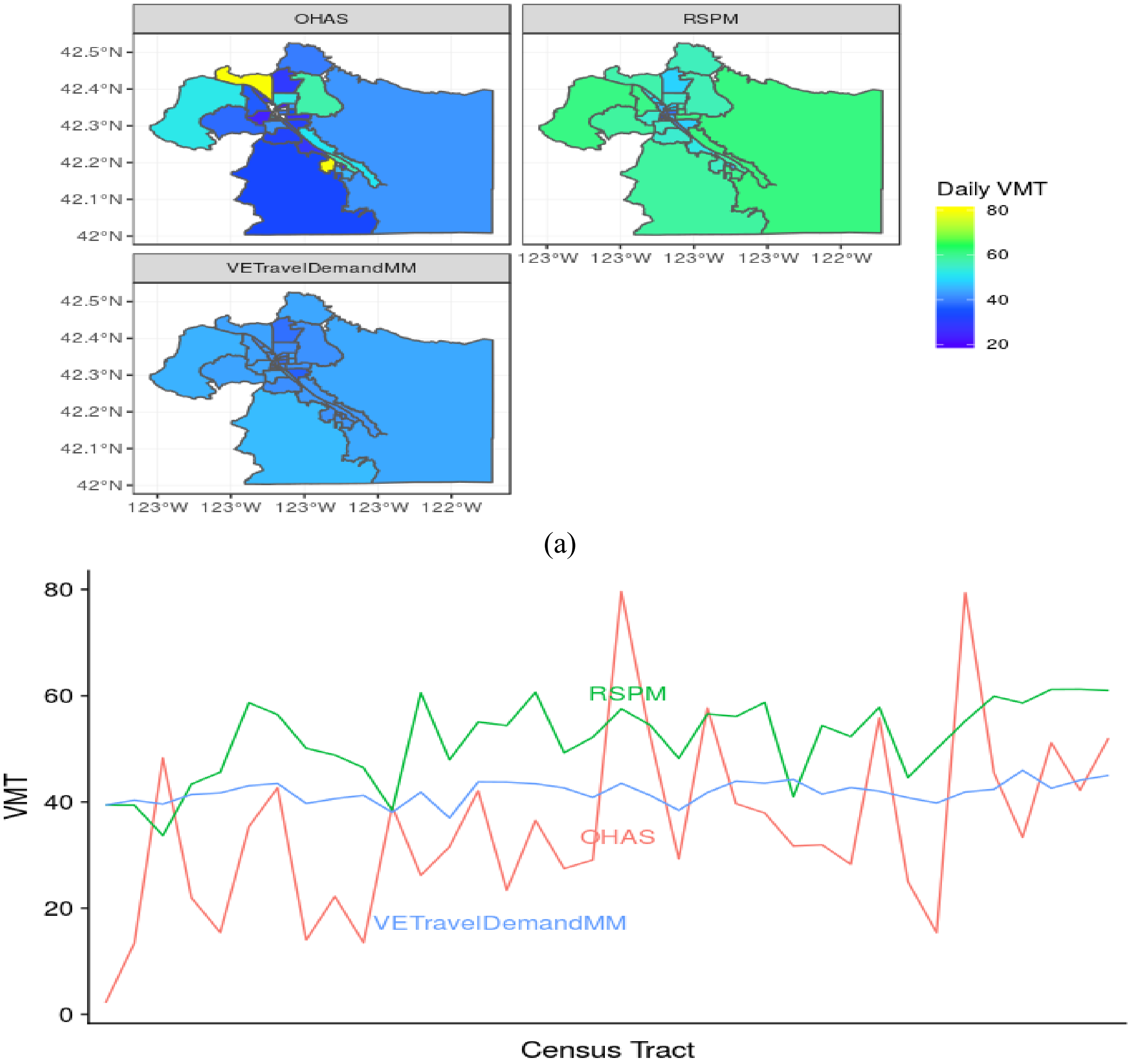
**Table 4.21 OHAS Observations**

| | | | | Trips | | | | PMT | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Category** | **n** | **DVMT** | | **Bike Trips** | **Walk Trips** | **Transit Trips** | | **Bike PMT** | **Walk PMT** | **Transit PMT** |
| **Overall** | | | | | | | | | | |
| **RVMPO** | 931 | 36.700 | | 0.232 | 0.870 | 0.094 | | 0.395 | 0.276 | 0.538 |
| **DevelopmentType** | | | | | | | | | | |
| **Rural** | 81 | 50.200 | | 0.159 | 0.435 | 0.008 | | 0.210 | 0.137 | 0.042 |
| **Urban** | 850 | 35.700 | | 0.237 | 0.901 | 0.100 | | 0.408 | 0.286 | 0.573 |
| **Income** | | | | | | | | | | |
| **<$40k** | 367 | 27.200 | | 0.138 | 0.798 | 0.144 | | 0.164 | 0.222 | 0.762 |
| **$40k-$80k** | 329 | 39.100 | | 0.455 | 0.777 | 0.014 | | 0.763 | 0.313 | 0.050 |
| **>$80k** | 235 | 53.900 | | 0.072 | 1.186 | 0.114 | | 0.300 | 0.336 | 0.845 |
| **Population per Square Mile** | | | | | | | | | | |
| **<1k** | 226 | 40.800 | | 0.079 | 0.510 | 0.037 | | 0.270 | 0.135 | 0.013 |
| **1k-5k** | 460 | 37.100 | | 0.361 | 0.891 | 0.084 | | 0.595 | 0.304 | 0.495 |
| **5k-10k** | 232 | 32.800 | | 0.167 | 1.036 | 0.145 | | 0.222 | 0.310 | 0.979 |
| **>10k** | 13 | 43.500 | | 0.000 | 1.408 | 0.076 | | 0.000 | 0.528 | 0.055 |

### 4.3.4 Comparison of Spatial Distribution (Census Tract)

#### *4.3.4.1 VMT*

The spatial distribution of (weighted) average VMT from the observed OHAS data is very noisy due to small sample size per census tract (min=4, mean=25.861, and max=81). It is also different in what is predicted. The new VETravelDemandMM module predicts Annual Average Daily VMT (AADVMT) for households, the RSPM simulates AADVMT from household DVMT predictions, while OHAS reports household VMT on the day of the survey. The RSPM predictions are higher than the AADVMT predictions from VETravelDemandMM.



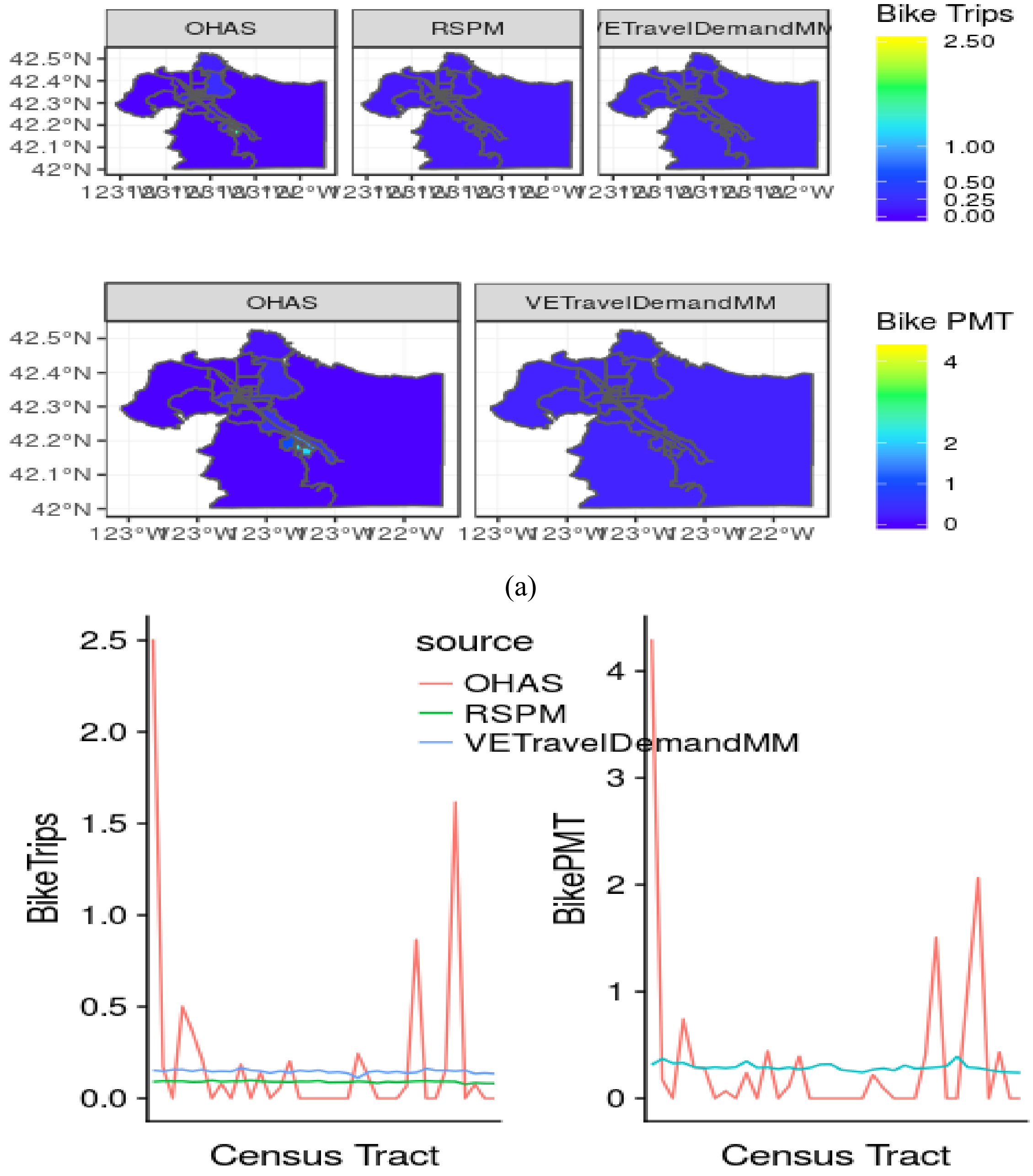
(a)

(b)

**Figure 4.5 Maps (a) and line chart (b) of VMT by Census Tract from RSPM, VETravelDemand, and OHAS**

#### *4.3.4.2 Bike Trips and PMT*

Similar to VMT, the spatial distribution of (weighted) average bike trips and PMT from the observed OHAS data is very noisy. The VETravelDemandMM has larger predictions than RSPM for all tracts, even though the magnitude of the difference is small.



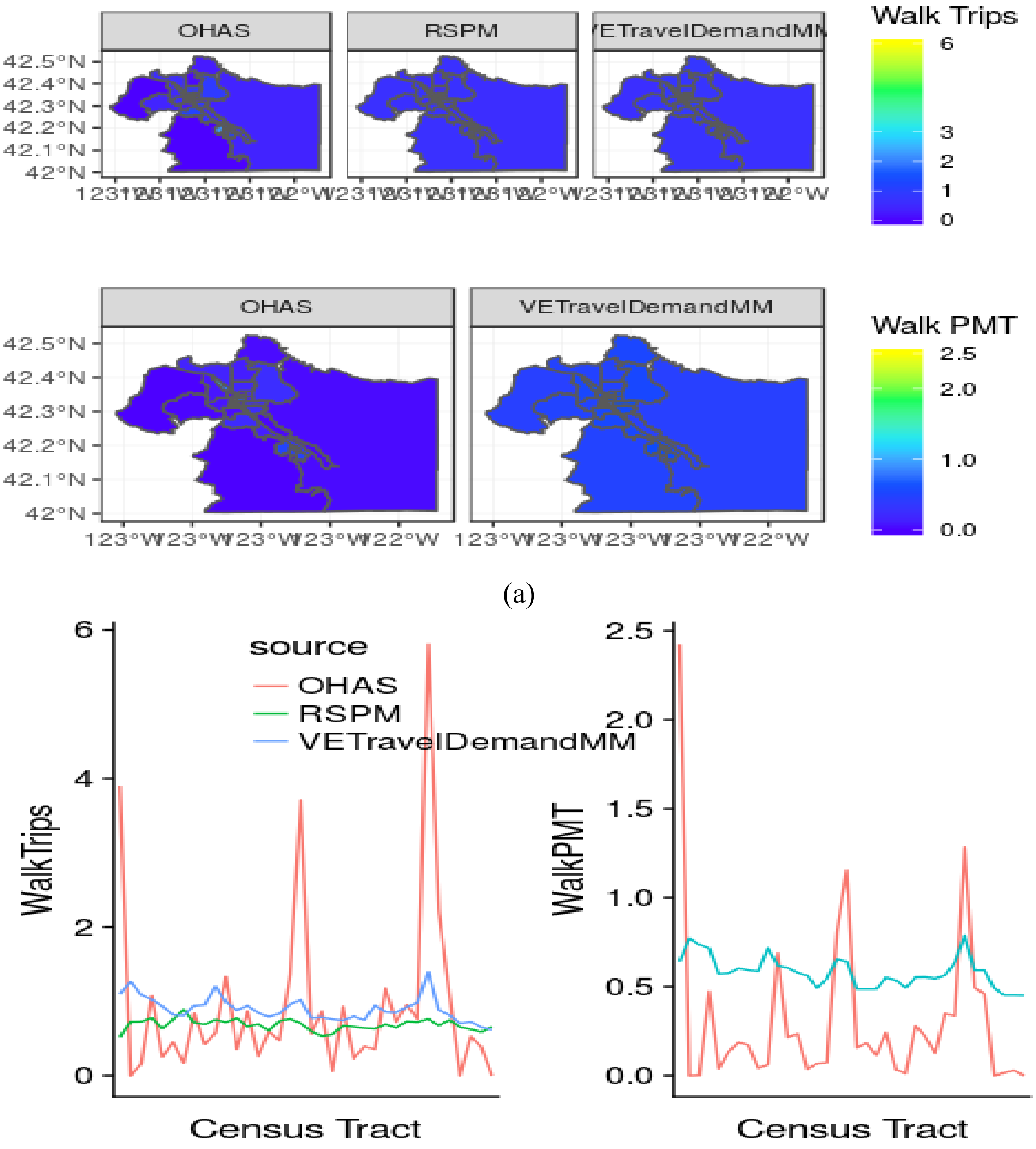
(a)

(b)

**Figure 4.6 Maps (a) and line chart (b) of bike trips and PMT by Census Tract from RSPM, VETravelDemand, and OHAS**

#### *4.3.4.3 Walk Trips and PMT*

The spatial distribution of (weighted) average walk trips and PMT from the observed OHAS data is again very noisy. The VETravelDemandMM has slightly larger predictions than RSPM for all tracts. The VETravelDemandMM successfully predicts tracts with higher observed walk trips and PMT, even though the magnitude differs.



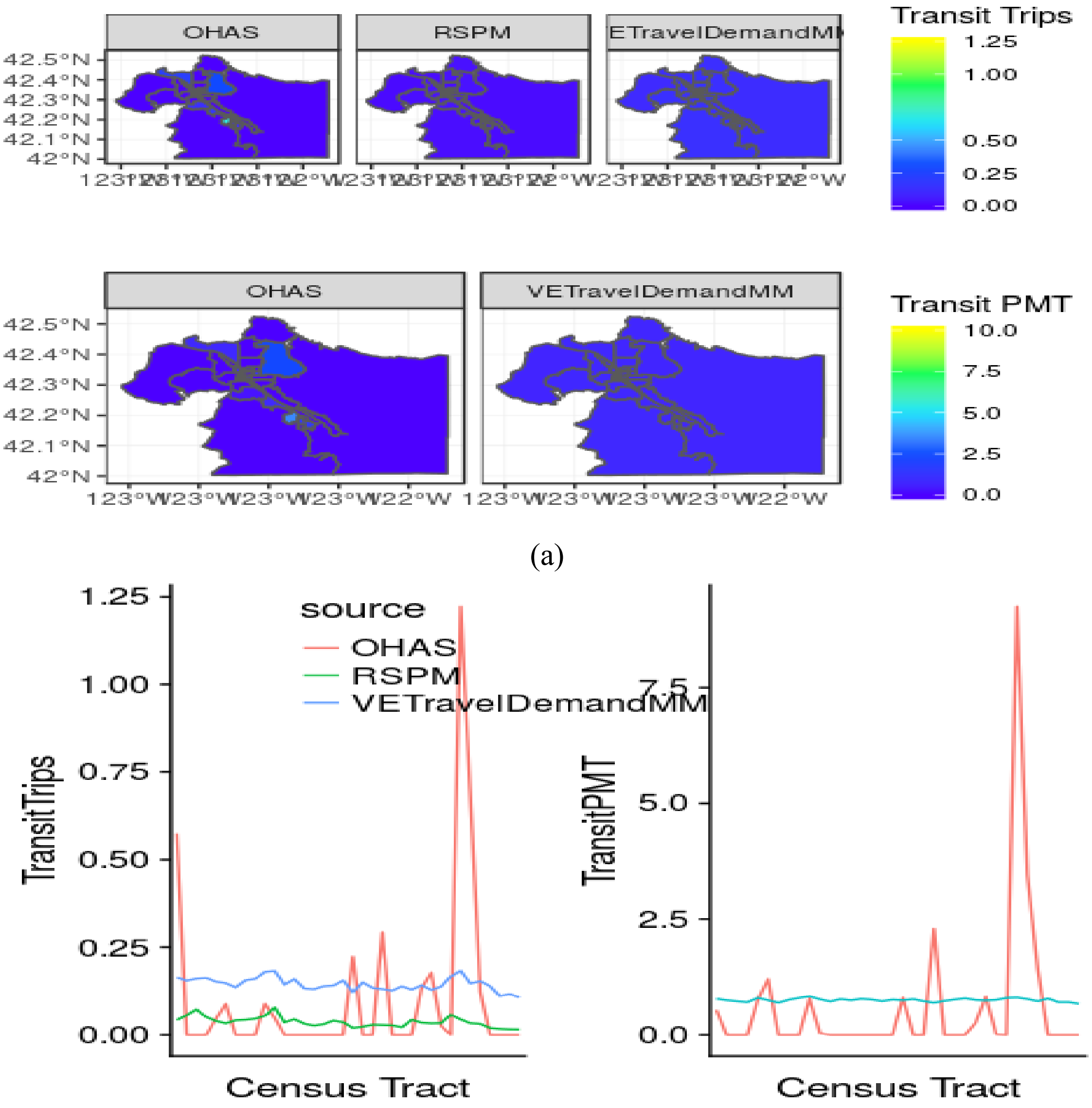
(a)

(b)

**Figure 4.7 Maps (a) and line chart (b) of walk trips and PMT by Census Tract from RSPM, VETravelDemand, and OHAS**

#### *4.3.4.4 Transhit Trips and PMT*

There is a large number of tracts without any observed transit trips or PMT from the observed OHAS data, which seems reasonable as not all tracts have transit service in Rogue Valley. However, neither the VETravelDemandMM nor the RSPM is able to replicate this pattern as variables for transit supply are not used in the prediction. The VETravelDemandMM predicts slightly larger quantity than RSPM for all tracts with little variation across census tracts.



(a)

(b)

**Figure 4.8 Maps (a) and line chart (b) of transit trip and PMT by Census Tract from RSPM, VETravelDemand, and OHAS**

## 4.4 PHASE III

All modules in the VETravelDemandMM R package have been tested to work with the develop branch of VisionEval using the RVMPO data. Automated testing (continuous integration) have been put in place to make sure the code/package passes all tests and is in working condition with the latest version of VisionEval all the time. And if anything breaks automated tests, authors of the packages will be notified through email (see also Task 3).

# 5.0 VETRAVELDEMANDMM MODULE ACCEPTANCE REVIEW

This chapter is adapted from the vignette in the VETravelDemandMM package documenting responses to VisionEval Contribution Review Criteria for the VETravelDemandMM module.

## 5.1 CONTRIBUTION REVIEW CRITERIA

1. Does it contain all the elements that are required by the VisionEval system specifications?

As a module for VisionEval and a standard R package, this package/module conforms to the recommendations in Section 8 Module, in terms of both required elements and the directories and files layout. The only directory included in the package but not appearing in the recommendation is data-raw. Here we follow Hadley Wickham's recommendation in his R packages: "Often, the data you include in data/ is a cleaned up version of raw data you've gathered from elsewhere. I highly recommend taking the time to include the code used to do this in the source version of your package [… and] put this code in data-raw/". The scripts in data-raw are the code used to estimate all models and save estimation results into the data directory.

2. Why is it better, and/or different than existing modules? Does it do good science and provide documentation justifying this claim? Is it consistent with good practice in strategic modeling? How might it overlap with existing modules?

The primary objectives of the module are to better represent multi-modal travel in models for strategic planning and to update models with the latest and best data available. In addition to these two primary objectives, the module uses rigorous selection and benchmarking of different model structures in choosing the model structure and takes advantage of R infrastructure and new packages. Justification and objectives can be found in these project reports:

- SPR 788 Project Report for Task 2 Model Design and Estimation Report
- SPR 788 Project Report for Task 3 VETravelDemand (VisionEval Travel Demand) Implementation
- SPR 788 Project Report for Task 4 Model Testing

3. Is the module documentation complete? Does it include documentation of model estimation, algorithms, and instructions for using?

There are documents of the module in various forms:

- Manual for each of the R functions in the module;

- Vignettes (including this document) that provide a long-form document of the package;

- Code and comments for estimation scripts

- Project reports and manuscripts under review, linked in the Introduction vignette

4. If the module allows the estimation of regional parameters, does it provide default data, does it have clear documentation of what the estimation data needs to be and how it is to be formatted and does it include proper data specifications to ensure that the user's input data are correct?

This module provides default model parameters estimated with US nationwide data, and it is also possible to re-estimate model parameters with region-specific data. The main estimation data are drawn from two external data package (NHTS2009 and SLD, documented therein) and data-raw/LoadDataforEstimation.R joins data from different data sources and creates a single household data frame for estimation. Data-raw/LoadDataforEstimation.R provides code and comments needed to replace the estimation data with region-specific data.

Since the model estimation does not use VisionEval specification, there is little check on data quality except for a few informational prints out in the script.

5. Is it based on geographic definitions that are consistent with the model system definitions?

The module uses two geographies: Bzone (block-group) and Marea (region/UZA), which are consistent with the model system definitions.

6. Does the module compute quickly enough and provide documentation justifying this claim?

The tests running all 6 models in the module using Rogue Valley data take between 1 minute to 1 minute and 30 seconds across different builds on Travis CI (See https://travis-ci.org/cities-lab/VETravelDemandMM/builds), on average 10 - 15 seconds per model, which is almost the same as the GreenSTEP/RSPM VETravelDemand module (https://travis-ci.org/gregorbj/VisionEval/builds).

7. Does it include all source files and data? If a contributed module does not include all source data, it should include a minimal example data file for testing and so it is clear what data structure is needed to run the module. It should also include clear instructions on how to fetch the data and/or a clear explanation of why non-included data is confidential and contact information for data owners.

Except for the confidential residential block group information for households in NHTS, all data and code are included in the package or in another open source (data) packages (NHTS2009 and SLD).

8. Does the module only call R code and packages that work on all operating systems? If the code includes any non-R code (e.g. FORTRAN, C++) will that code compile on all operating systems?

The module only includes R code and should work on all operating systems.

9. Is it licensed with the VisionEval license that allows the code to be freely distributed and modified and includes attribution so that the 'provenance' of the code can be tracked?

The package is licensed with the same Apache 2.0 license as VisionEval. A LICENSE file is added to the package directory.

10. Does it only interact with the computing environment by returning a properly structured list to the framework (i.e. it does not modify the global environment, does not read or write files, and only calls framework functions that are allowed)?

Primary functions of the module are implemented in R/Predict*.R. The development of the package follows the VisionEval system design guide and the template module and only calls framework functions and a few internal helper functions. The module does not modify the global environment or read/write files when running as a VisionEval module.

11. Does it include regression tests to enable checking that consistent results will be returned when updates are made to the framework and/or R programming environment?

checkModuleOutputs provided by testModule checks outputs against the specification of each model in automated tests of the package.

12. Does it include sufficient test coverage and test data? Does it pass the 'testModule' test which validates that it will run correctly in the model system?

Automated tests including devtools. Check (), installation testing, and test runs of models in the module with VisionEval::testModule () are in place with Travis-CI. All tests pass in the current and recent builds.

# 6.0 REFERENCES

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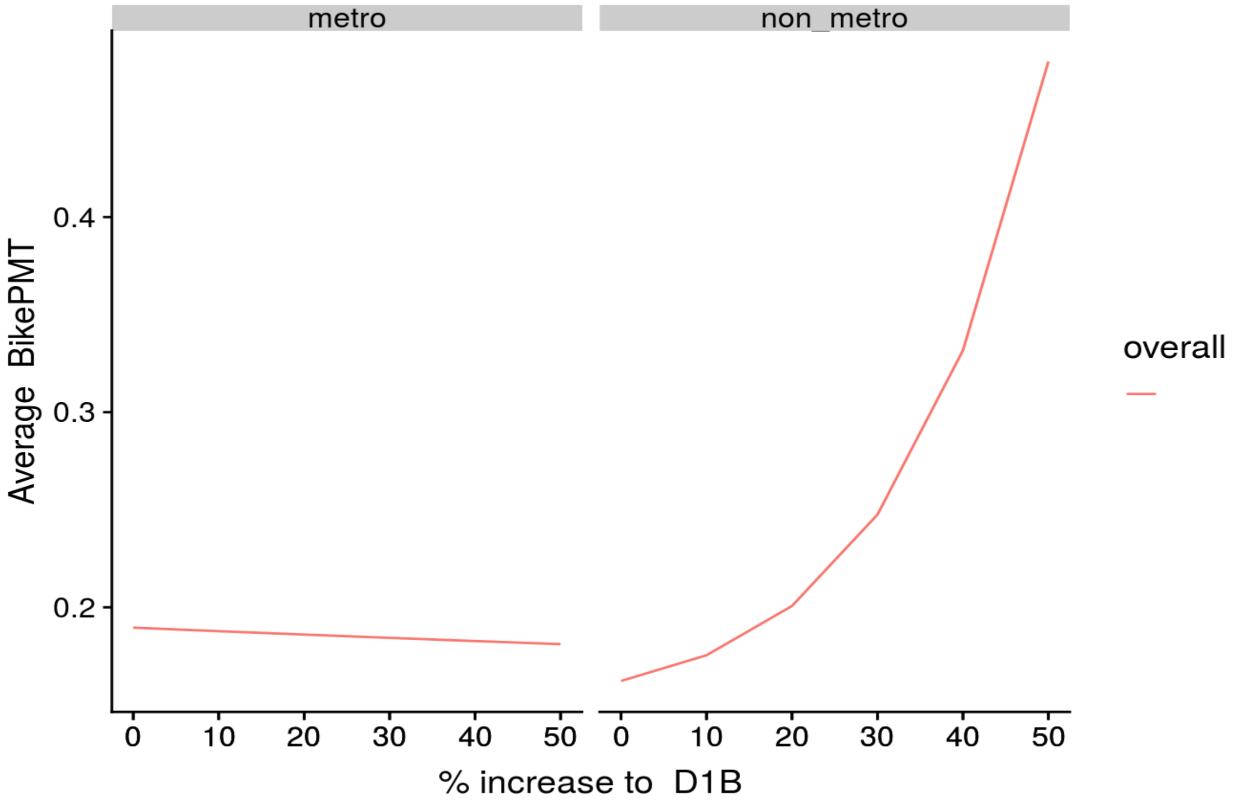
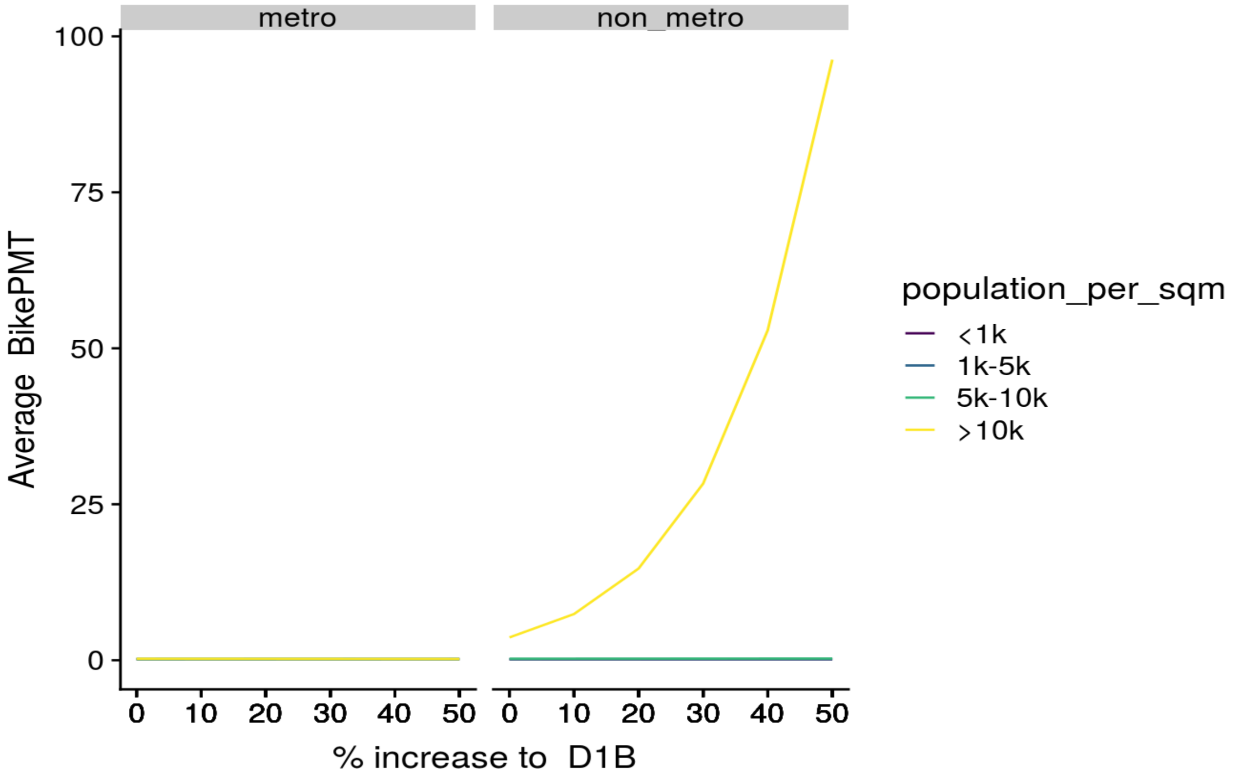
# APPENDIX A: ADDITIONAL FIGURES FOR MODEL TESTING


metro
non_metro
Average BikePMT
0.2
0.3
0.4
0 10 20 30 40 50
0 10 20 30 40 50
% increase to D1B
overall

(a)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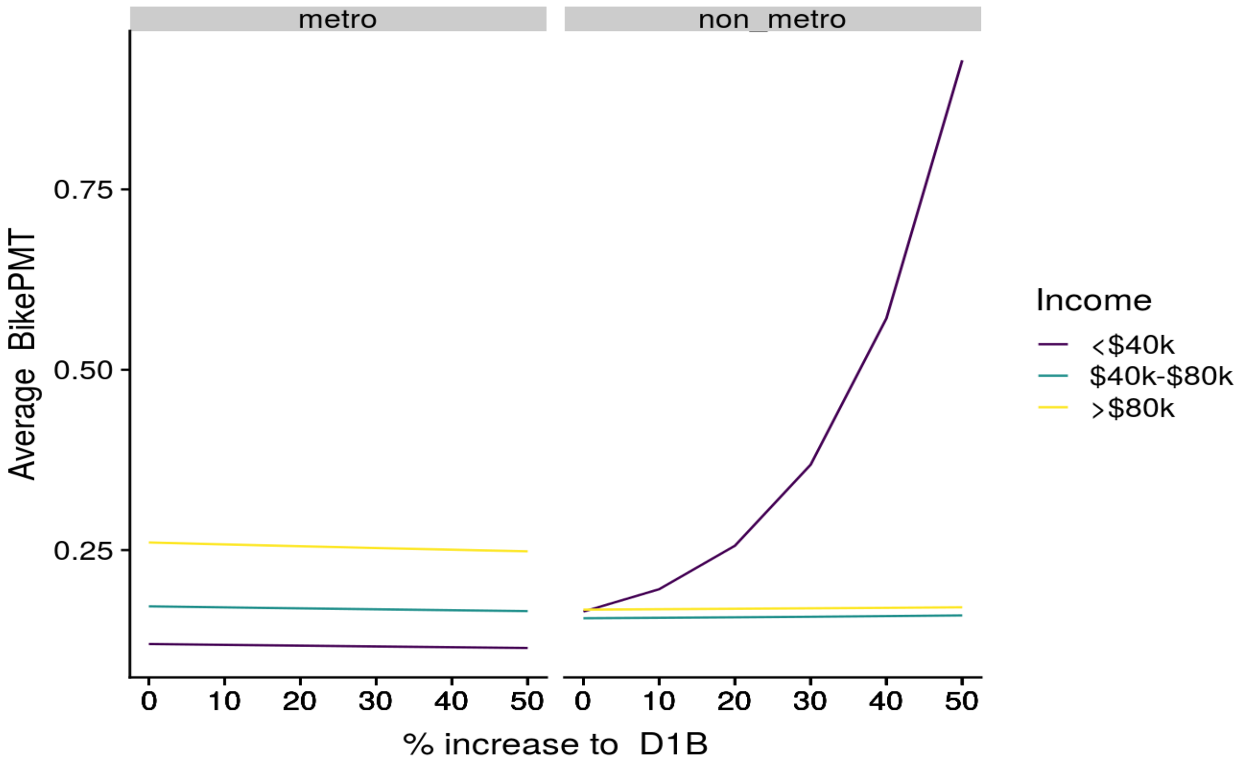
non_metro
Average BikePMT
0
25
50
75
100
0 10 20 30 40 50
0 10 20 30 40 50
% increase to D1B
population_per_sqm
<1k
1k-5k
5k-10k
>10k

(b)



(c)

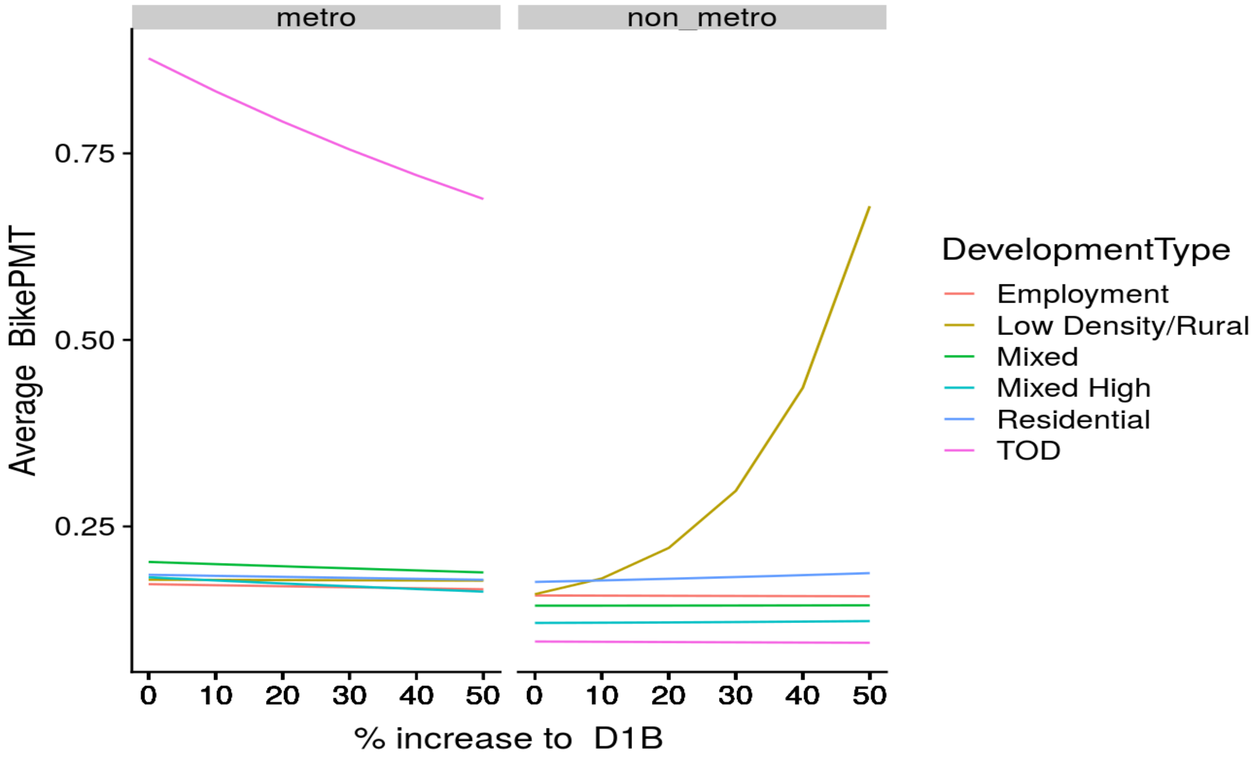
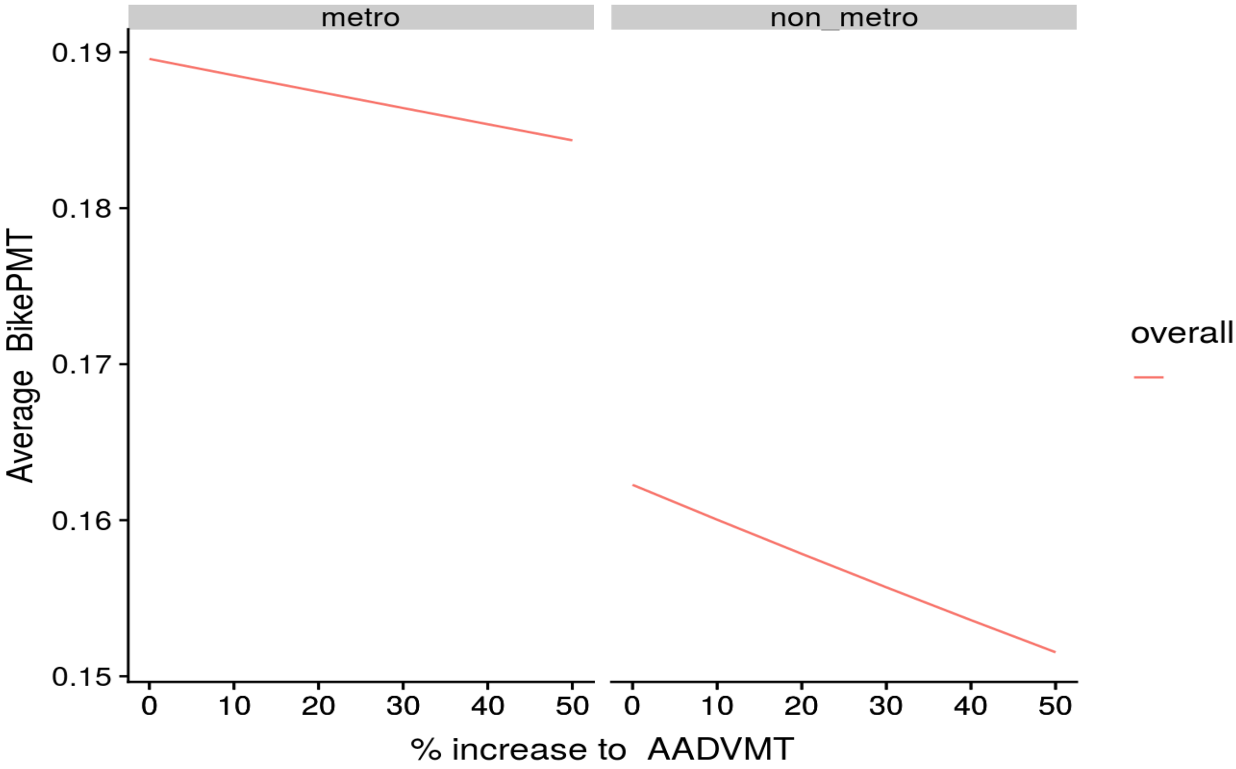
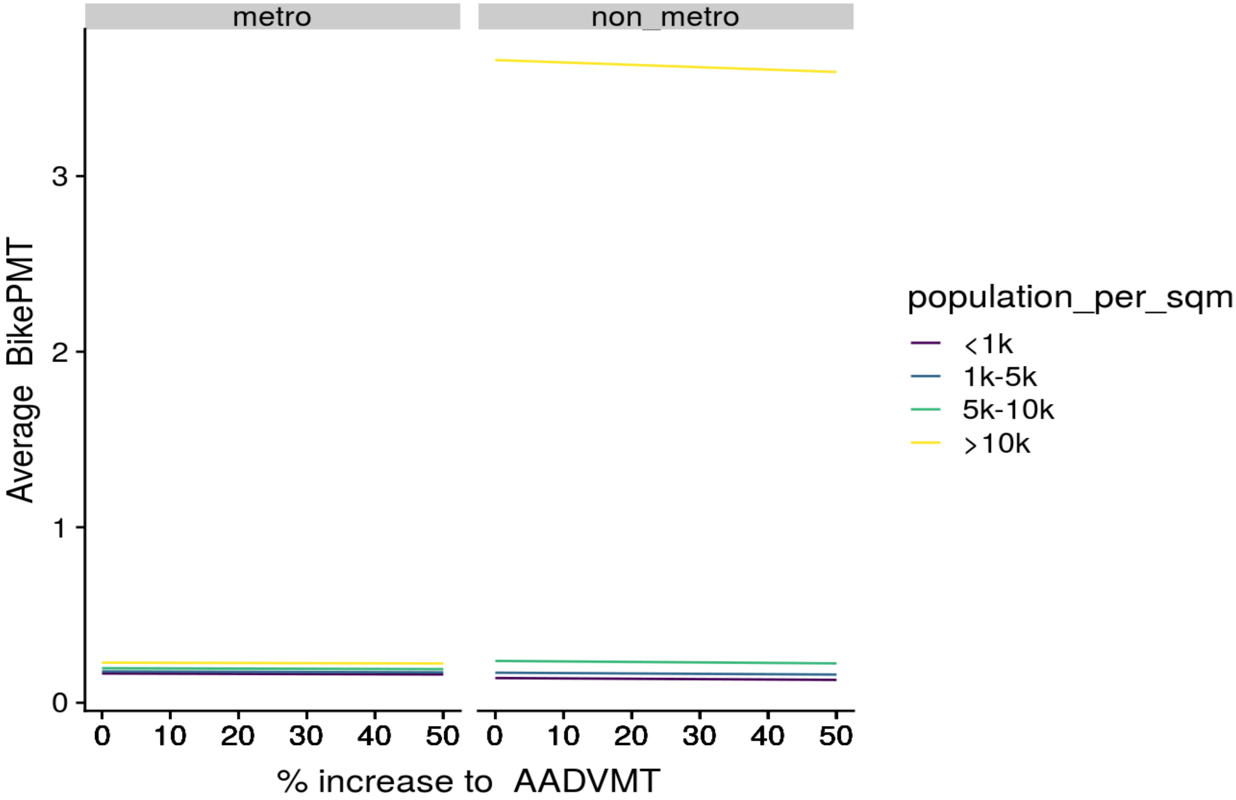


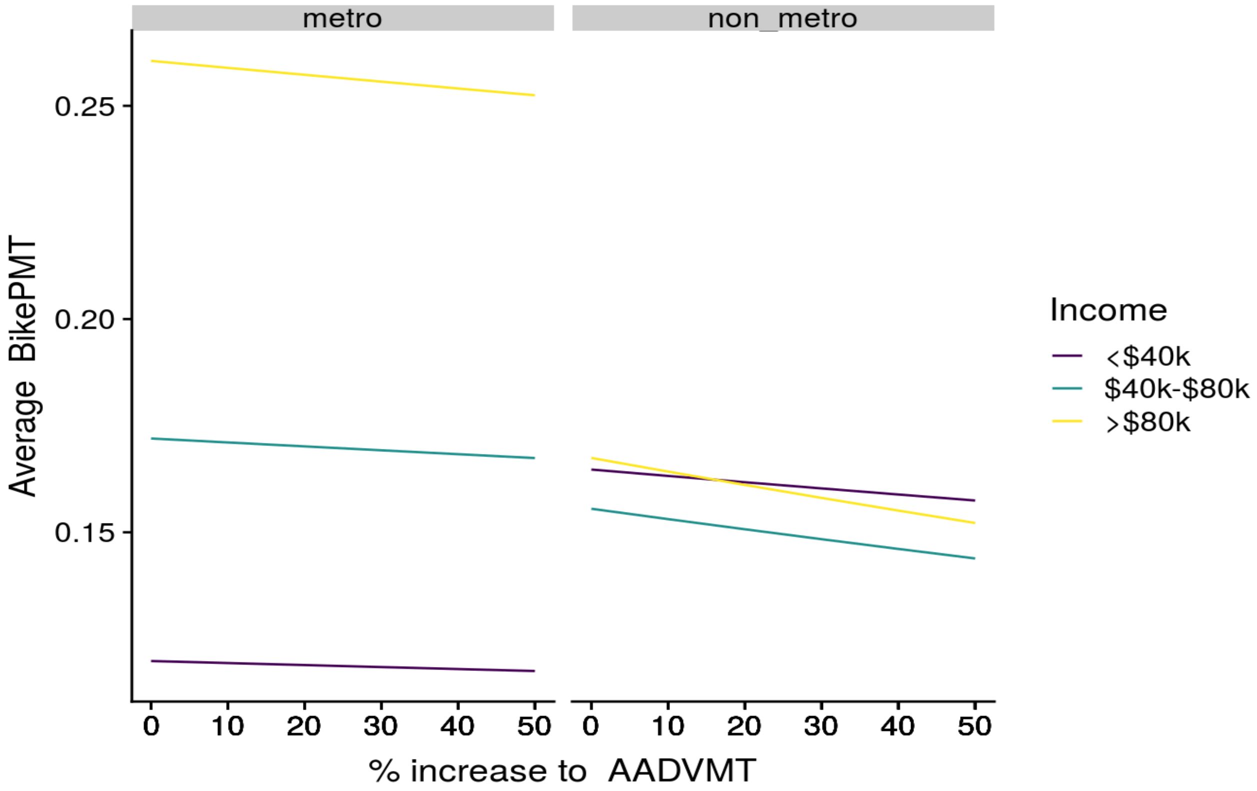
**Figure A.1 Elasticities of biking PMT with respect to D1B: overall (a), segmented by density (b), income (c) and development type (d)**


metro
non_metro
0.19
0.18
0.17
0.16
0.15
Average BikePMT
0
10
20
30
40
50
0
10
20
30
40
50
% increase to AADVMT
overall

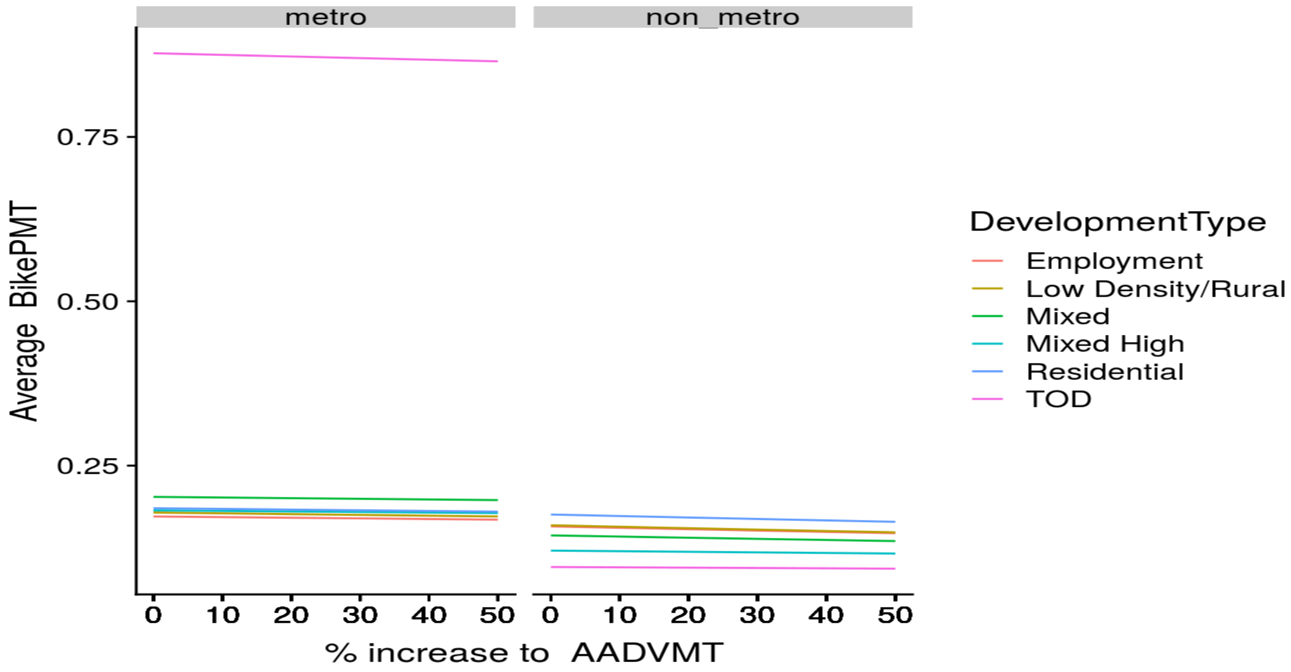
(a)


metro
non_metro
3
2
1
0
Average BikePMT
0
10
20
30
40
50
0
10
20
30
40
50
% increase to AADVMT
population_per_sqm
<1k
1k-5k
5k-10k
>10k

(b)

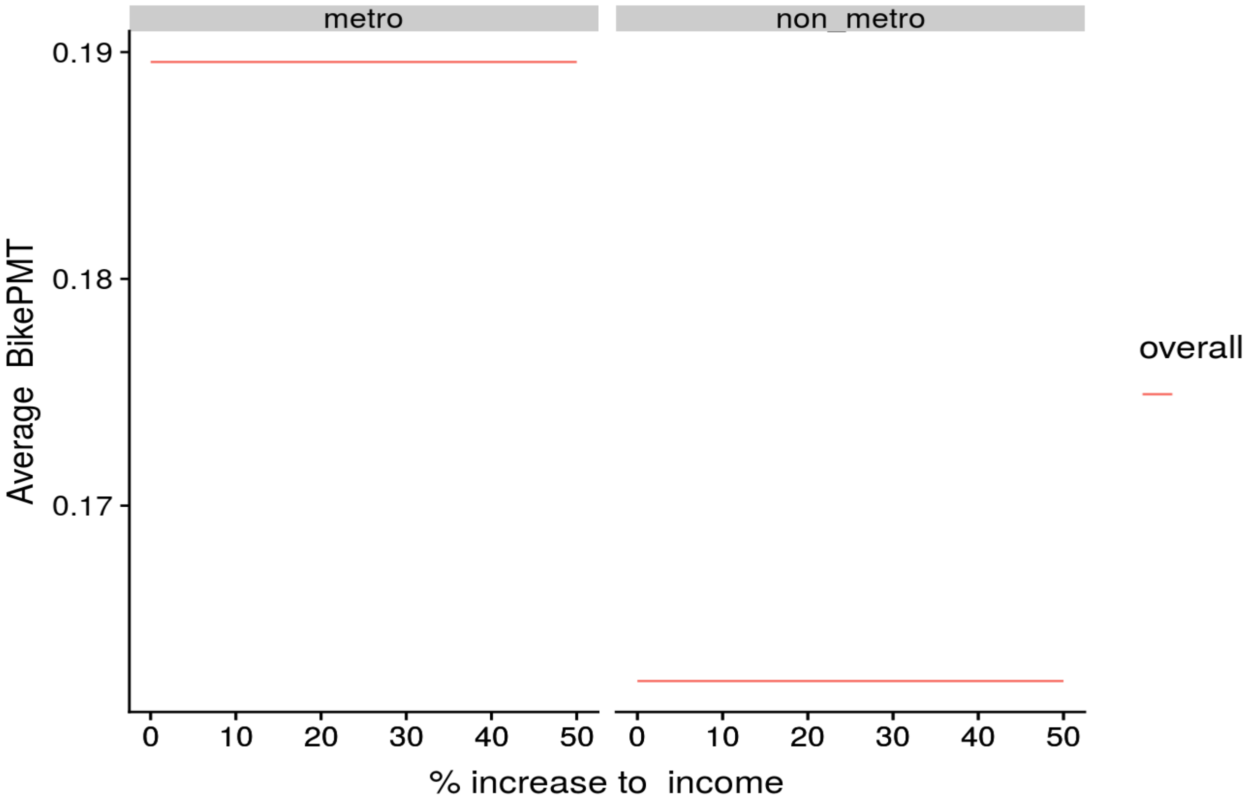


(c)

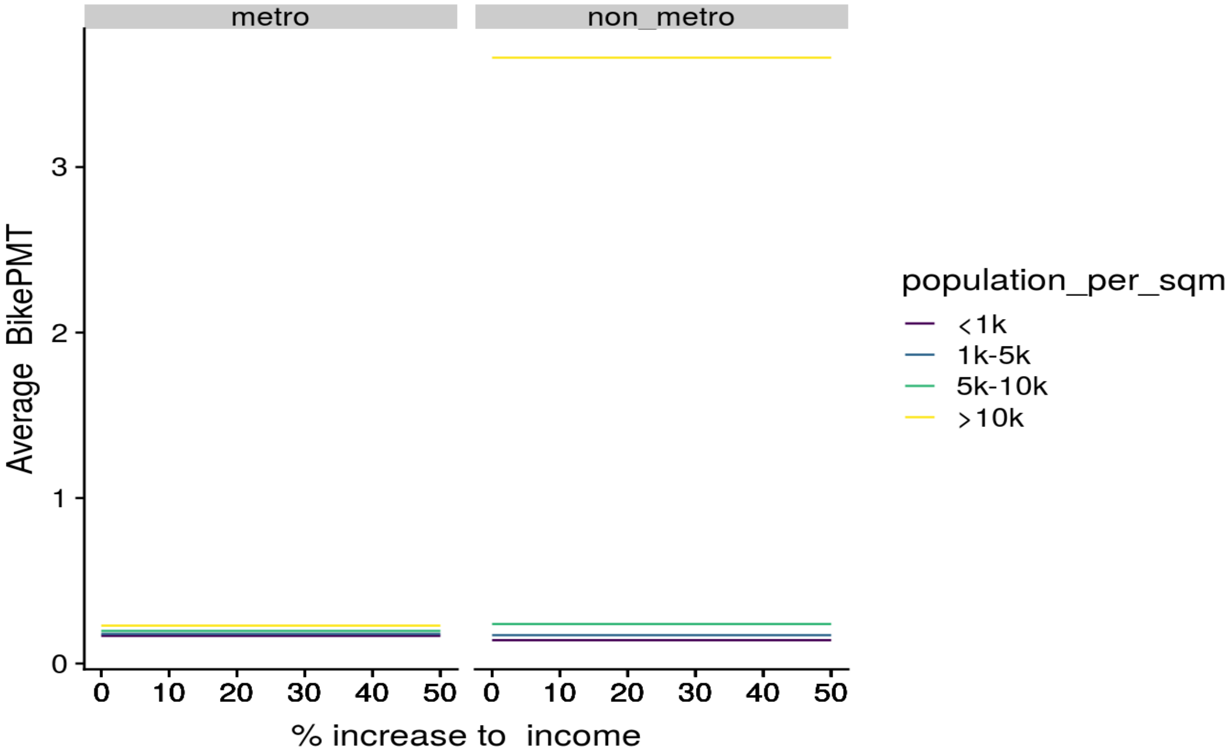


(d)

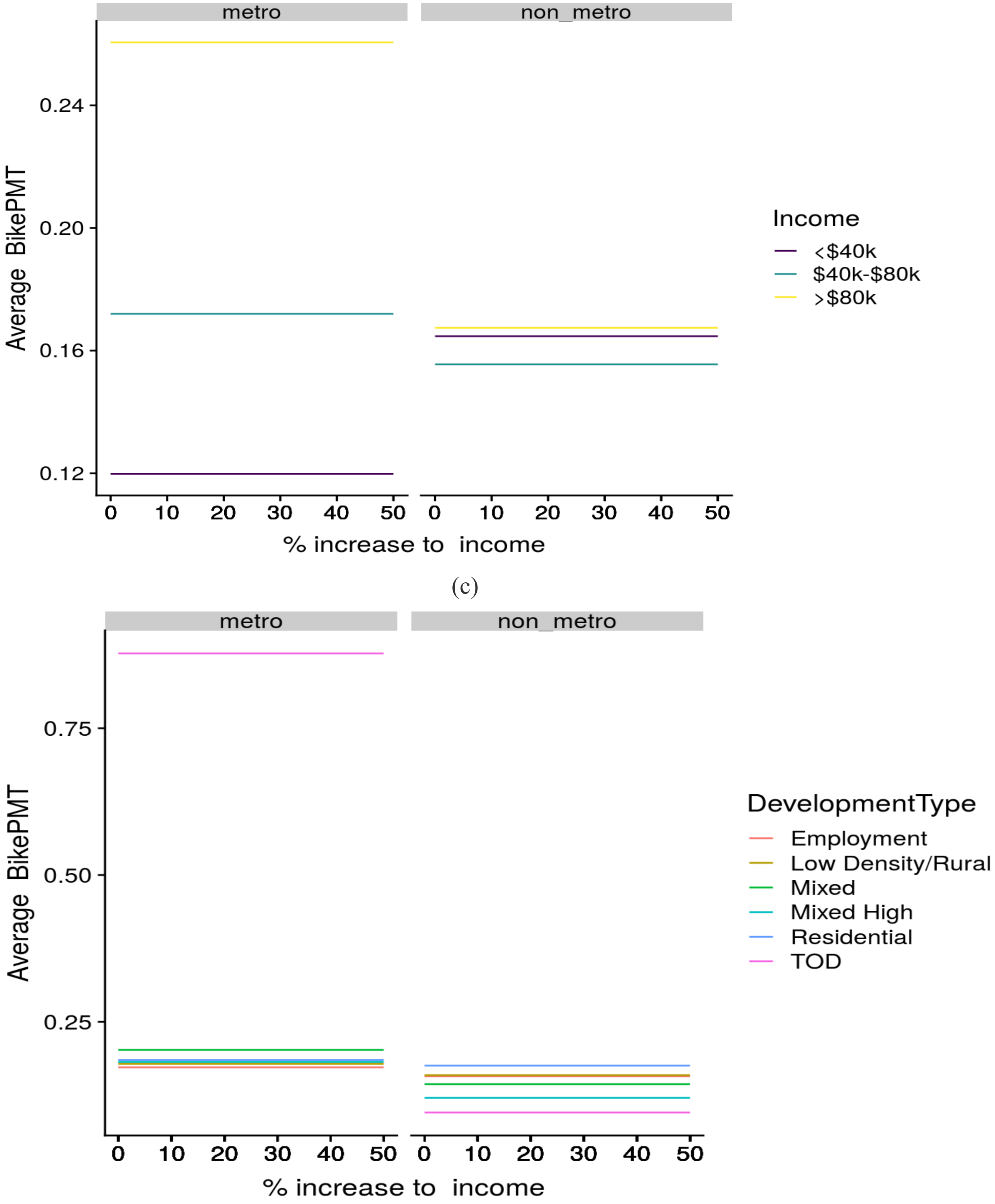
**Figure A.2 Elasticities of biking PMT with respect to AADVMT: overall (a), segmented by density (b), income (c) and development type (d)**


metro
non_metro
Average BikePMT
0.19
0.18
0.17
0
10
20
30
40
50
0
10
20
30
40
50
% increase to income
overall

(a)


metro
non_metro
Average BikePMT
3
2
1
0
0
10
20
30
40
50
0
10
20
30
40
50
% increase to income
population_per_sqm
<1k
1k-5k
5k-10k
>10k

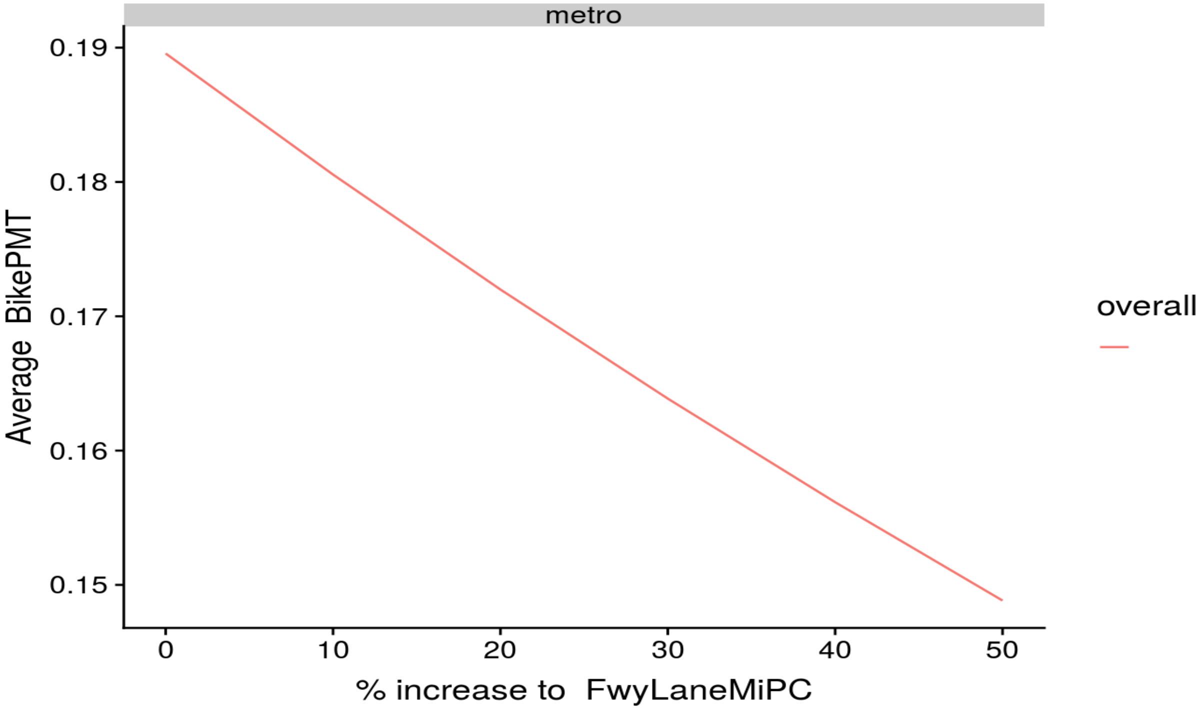
(b)



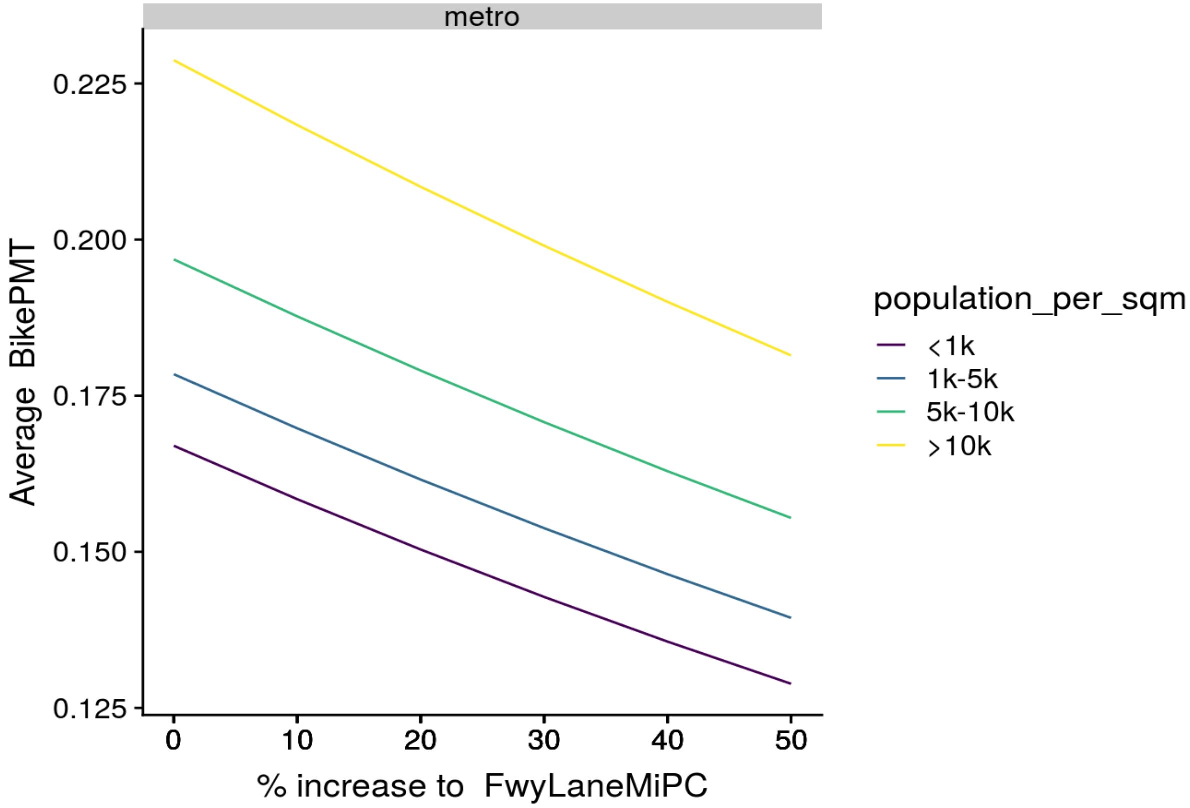
(c)

(d)

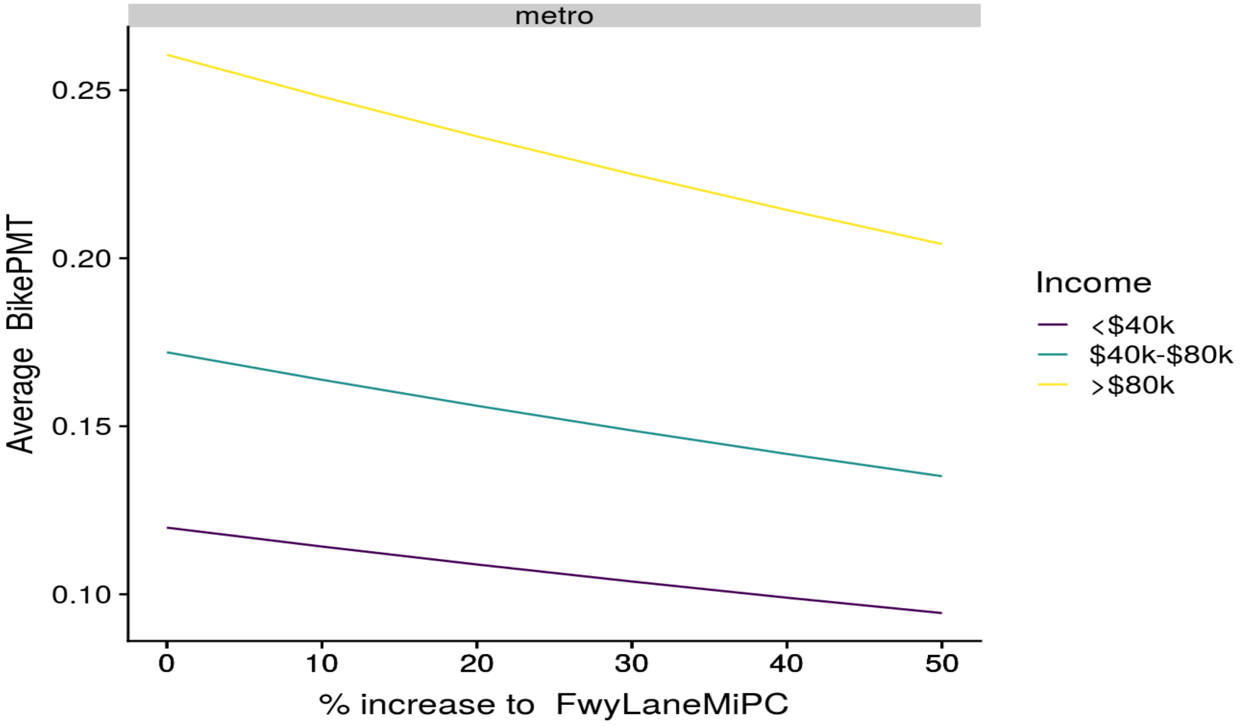
**Figure A.3 Elasticities of biking PMT with respect to household income: overall (a), segmented by density (b), income (c) and development type (d)**


metro
Average BikePMT
0.19
0.18
0.17
0.16
0.15
0
10
20
30
40
50
% increase to FwyLaneMiPC
overall

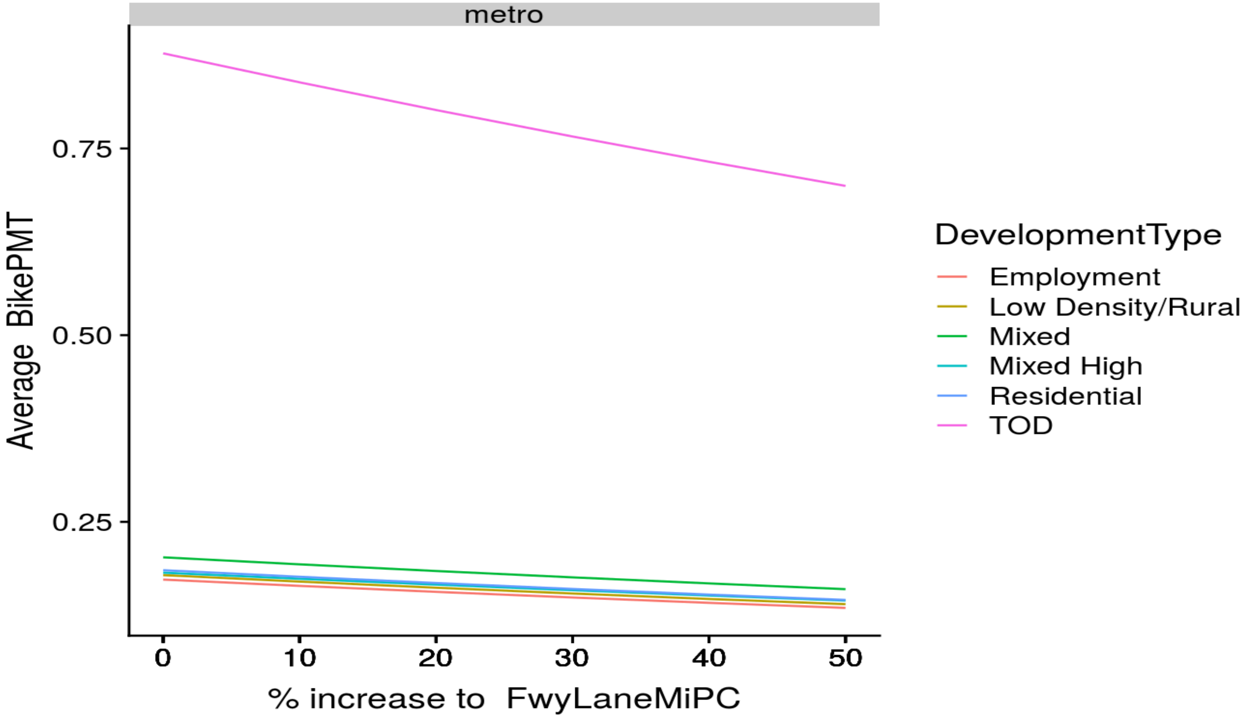
(a)


metro
Average BikePMT
0.225
0.200
0.175
0.150
0.125
0
10
20
30
40
50
% increase to FwyLaneMiPC
population_per_sqm
<1k
1k-5k
5k-10k
>10k

(b)

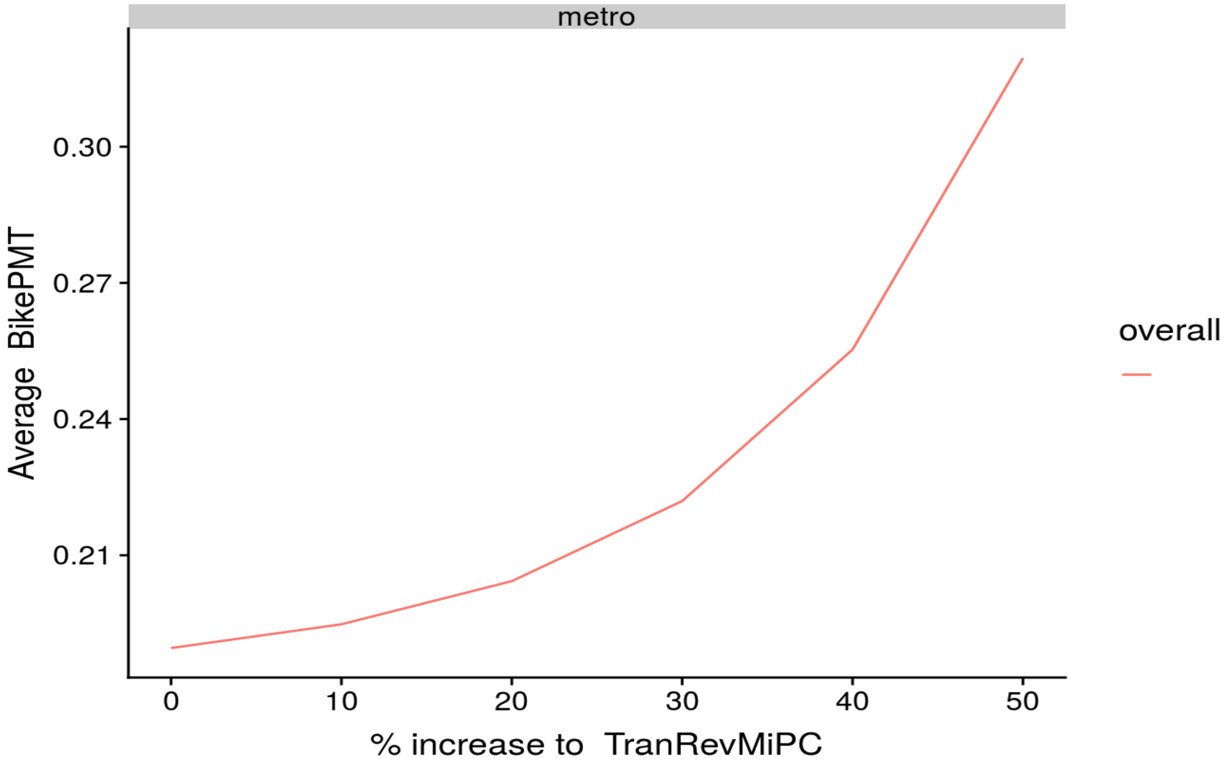


(c)

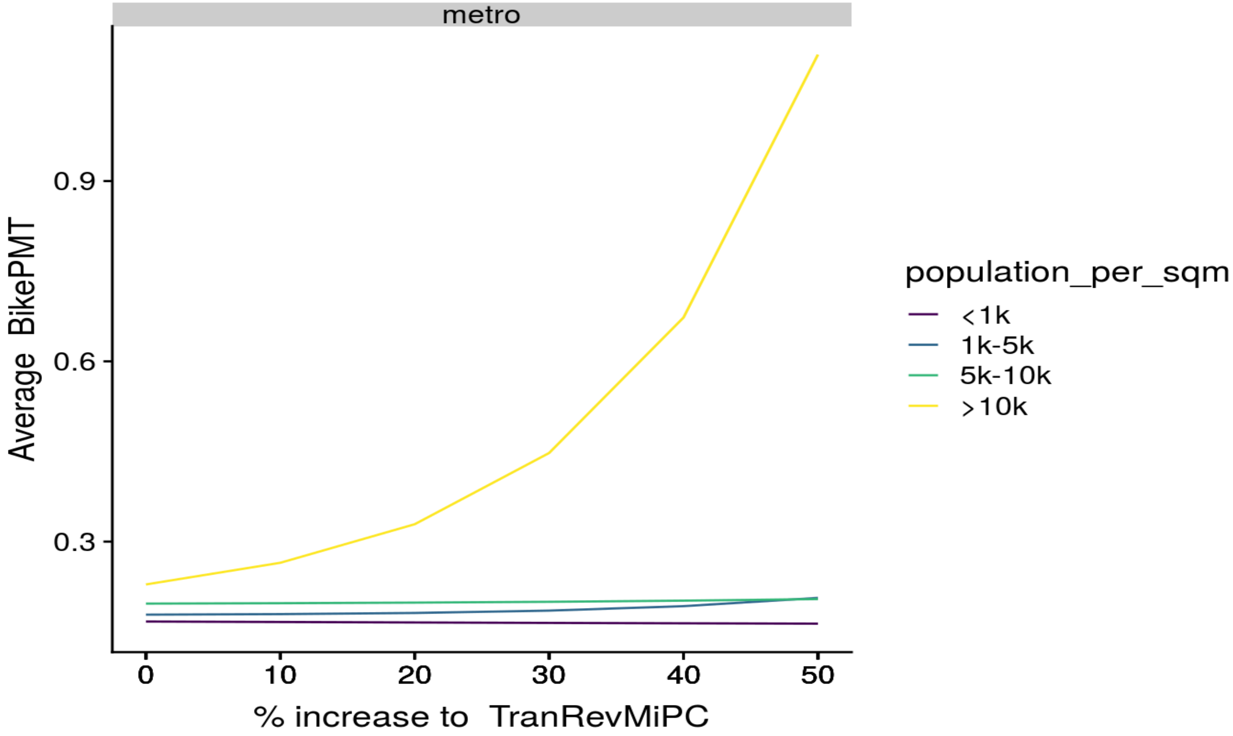


(d)

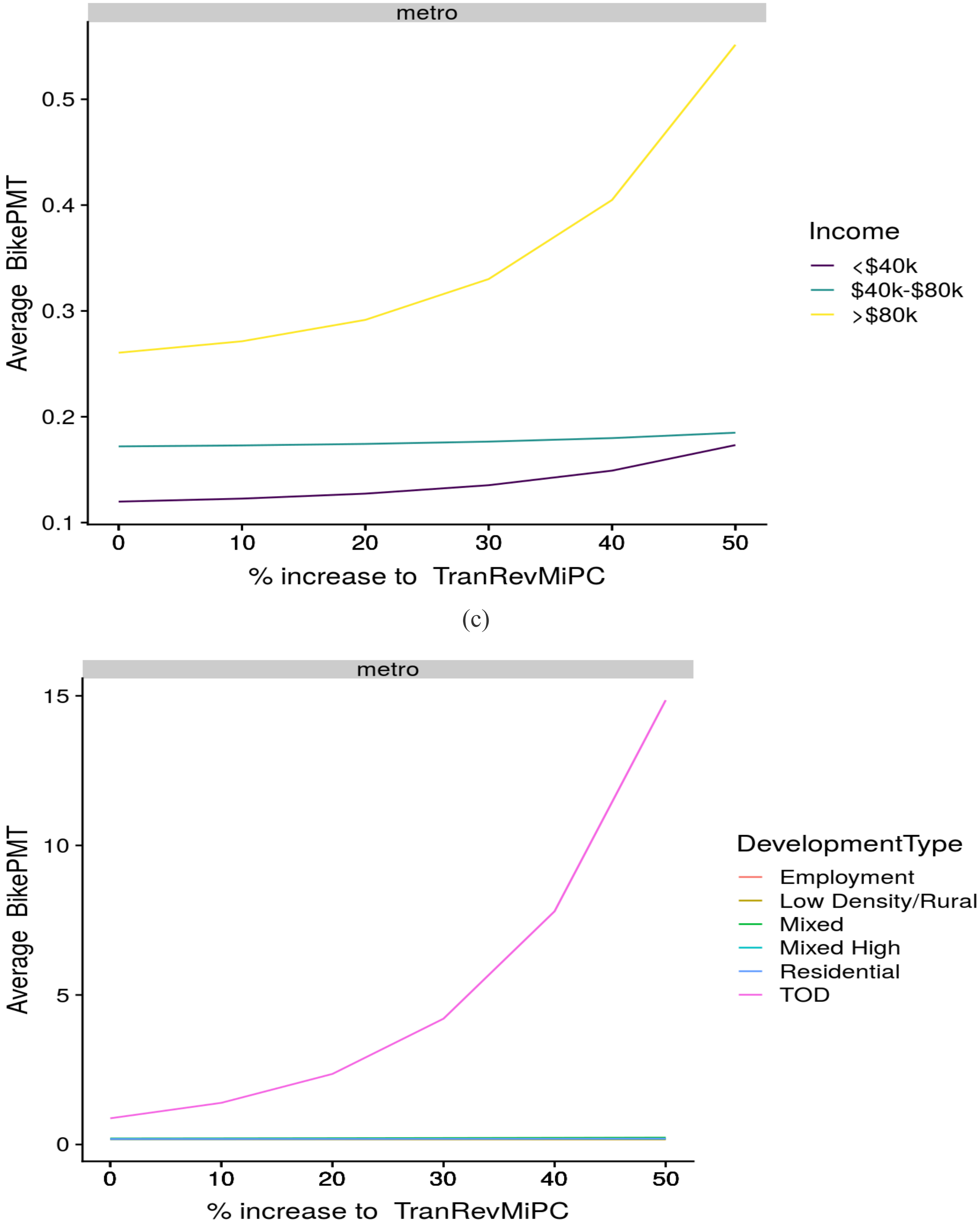
**Figure A.4 Elasticities of biking PMT with respect to Freeway lane miles per capita: overall (a), segmented by density (b), income (c) and development type (d)**


metro
Average BikePMT
0.30
0.27
0.24
0.21
0
10
20
30
40
50
% increase to TranRevMiPC
overall

(a)


metro
Average BikePMT
0.9
0.6
0.3
0
10
20
30
40
50
% increase to TranRevMiPC
population_per_sqm
<1k
1k-5k
5k-10k
>10k

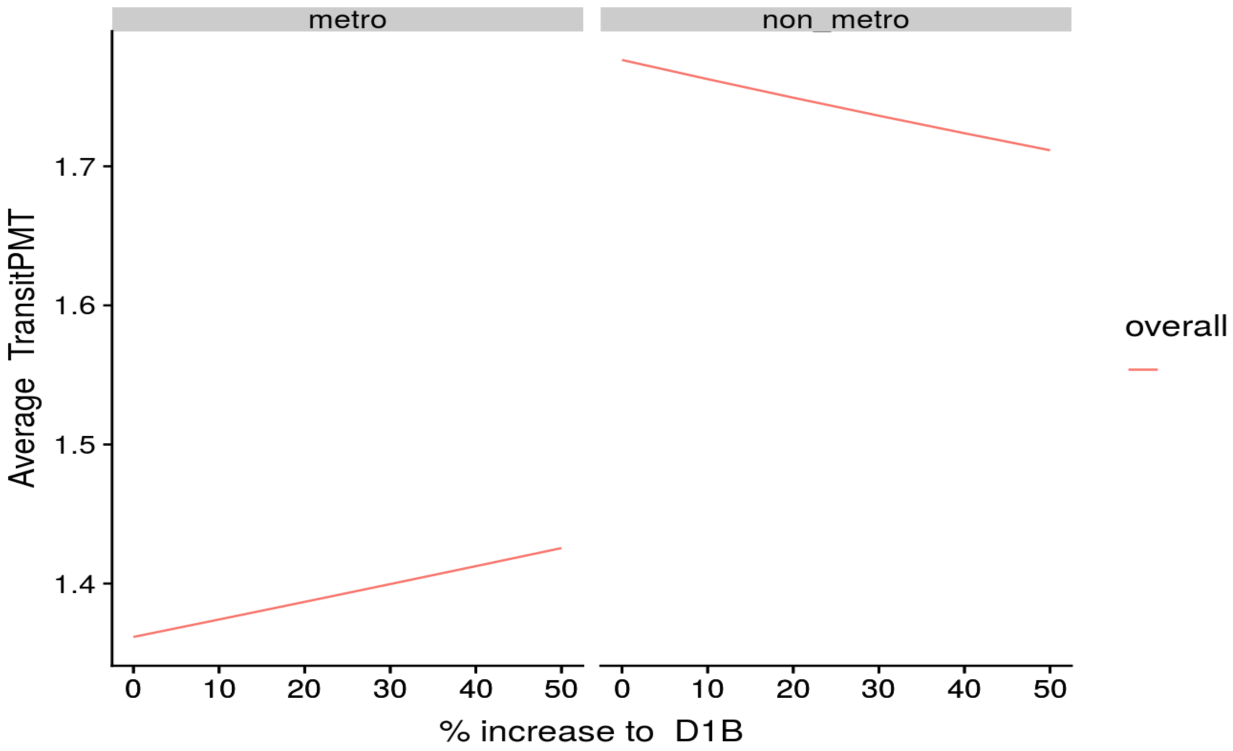
(b)



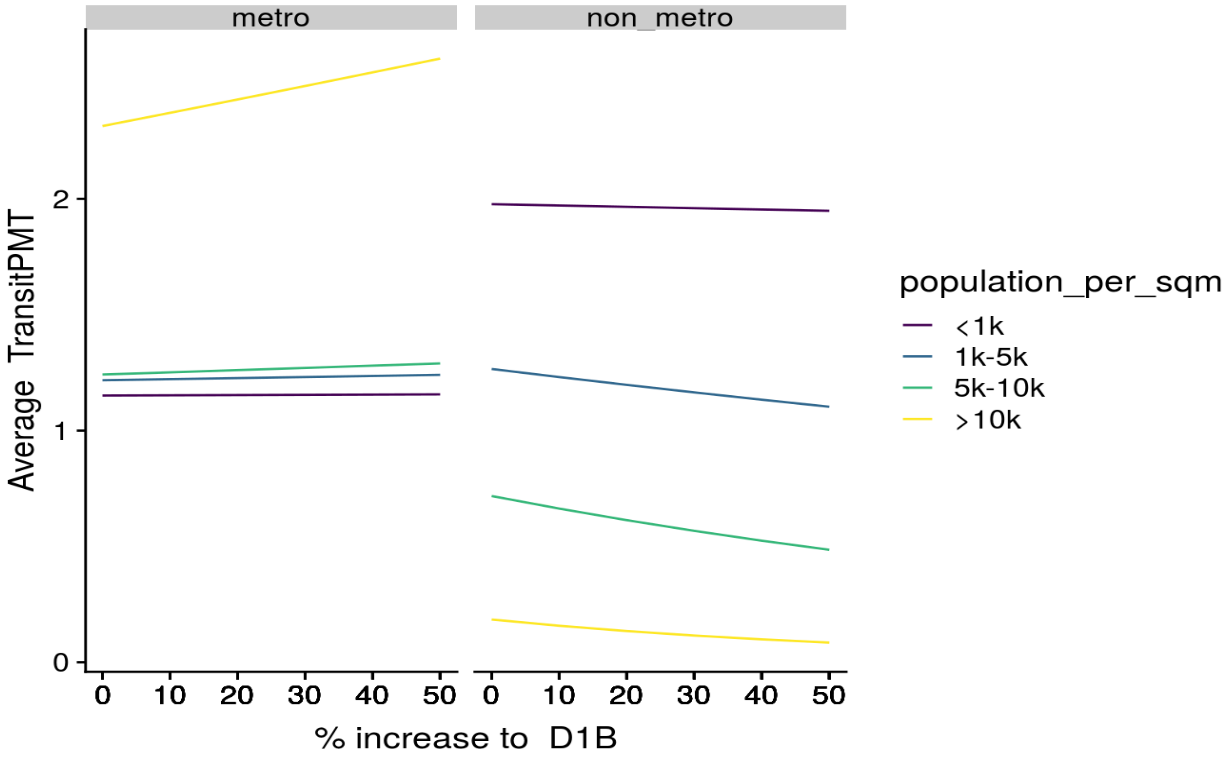
(c)

(d)

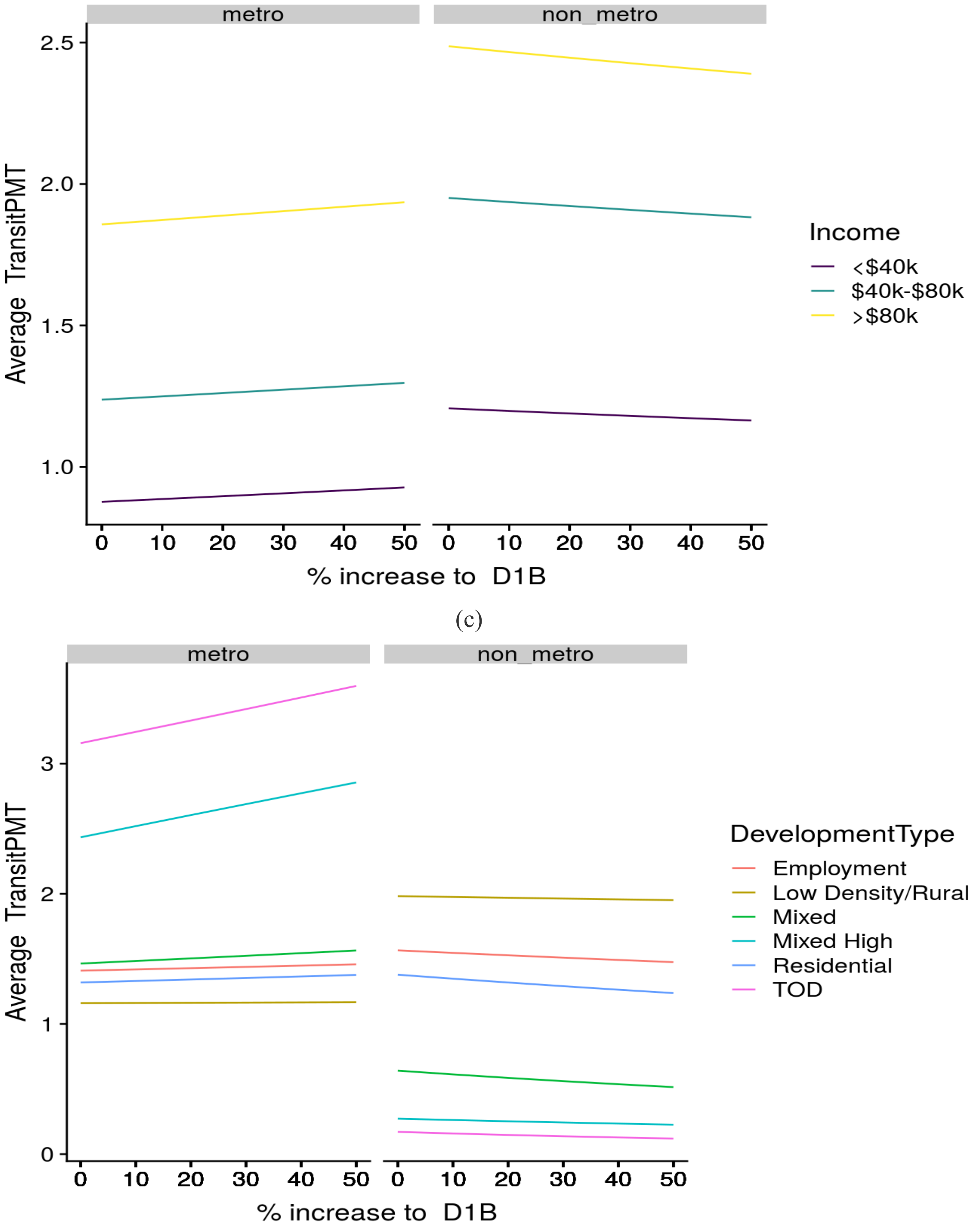
**Figure A.5 Elasticities of biking PMT with respect to transit revenue miles per capita: overall (a), segmented by density (b), income (c) and development type (d)**


metro
non_metro
Average TransitPMT
1.7
1.6
1.5
1.4
0
10
20
30
40
50
% increase to D1B
overall

(a)


metro
non_metro
Average TransitPMT
2
1
0
0
10
20
30
40
50
% increase to D1B
population_per_sqm
<1k
1k-5k
5k-10k
>10k

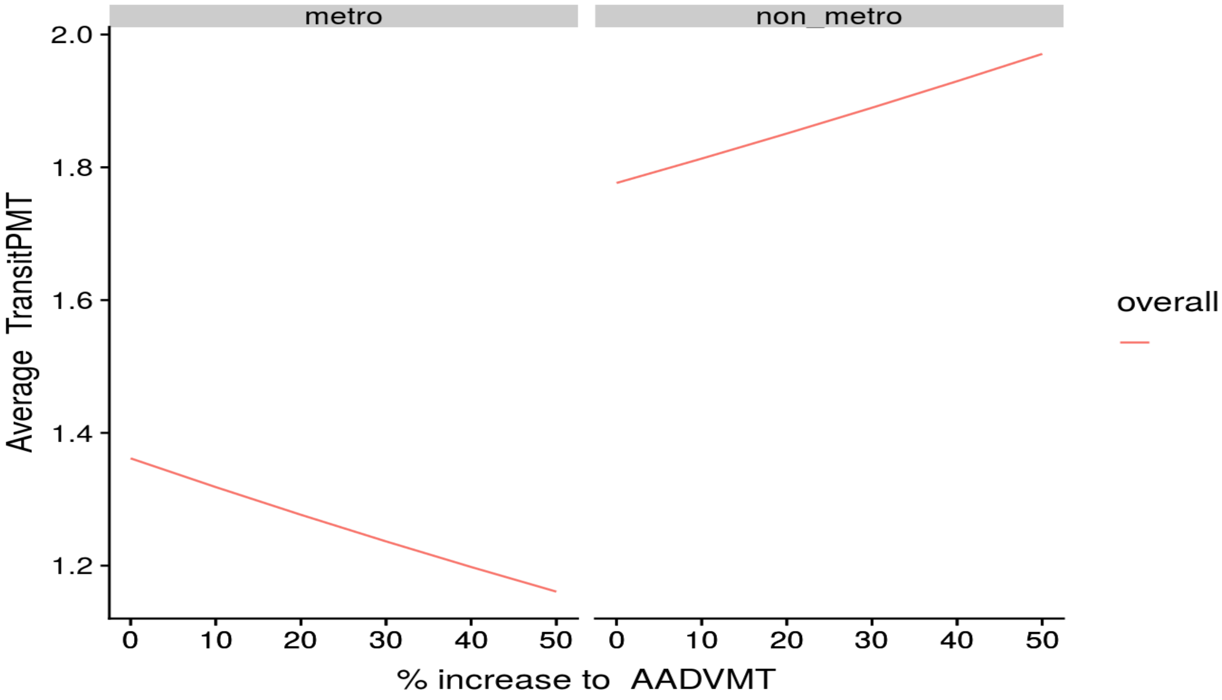
(b)



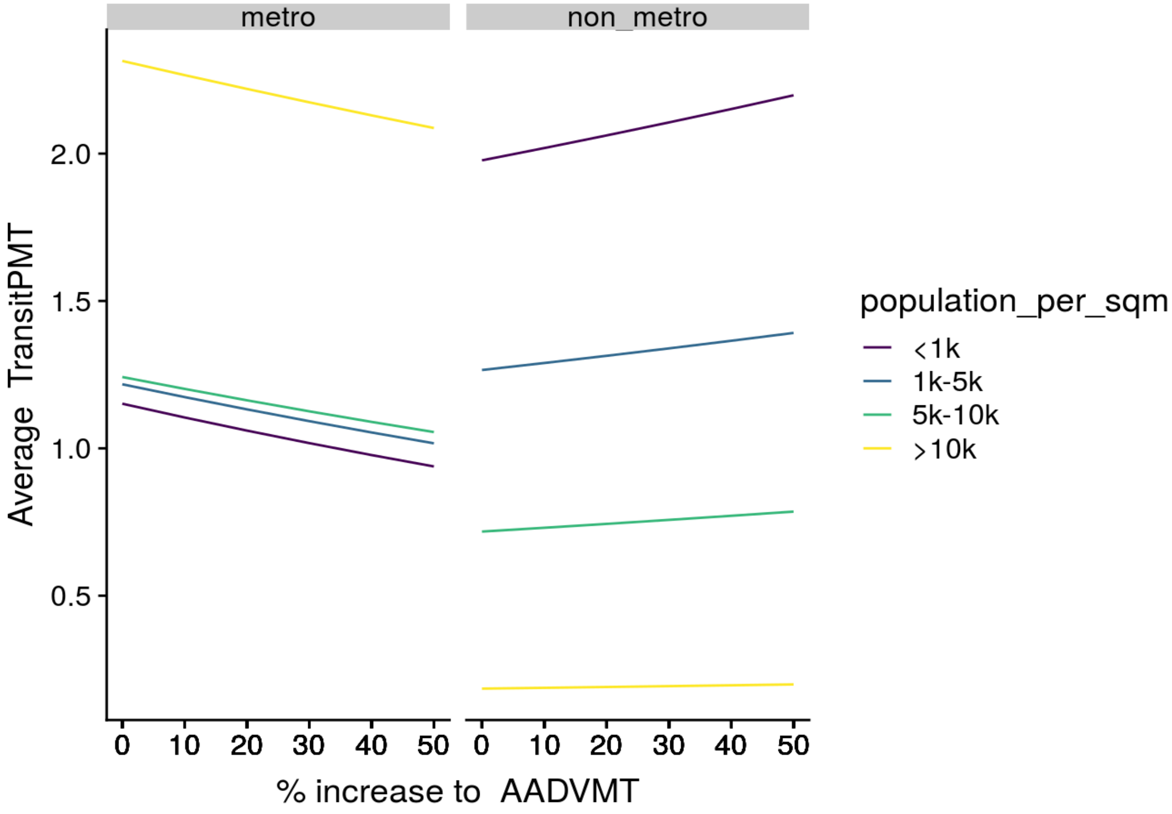
(c)

(d)

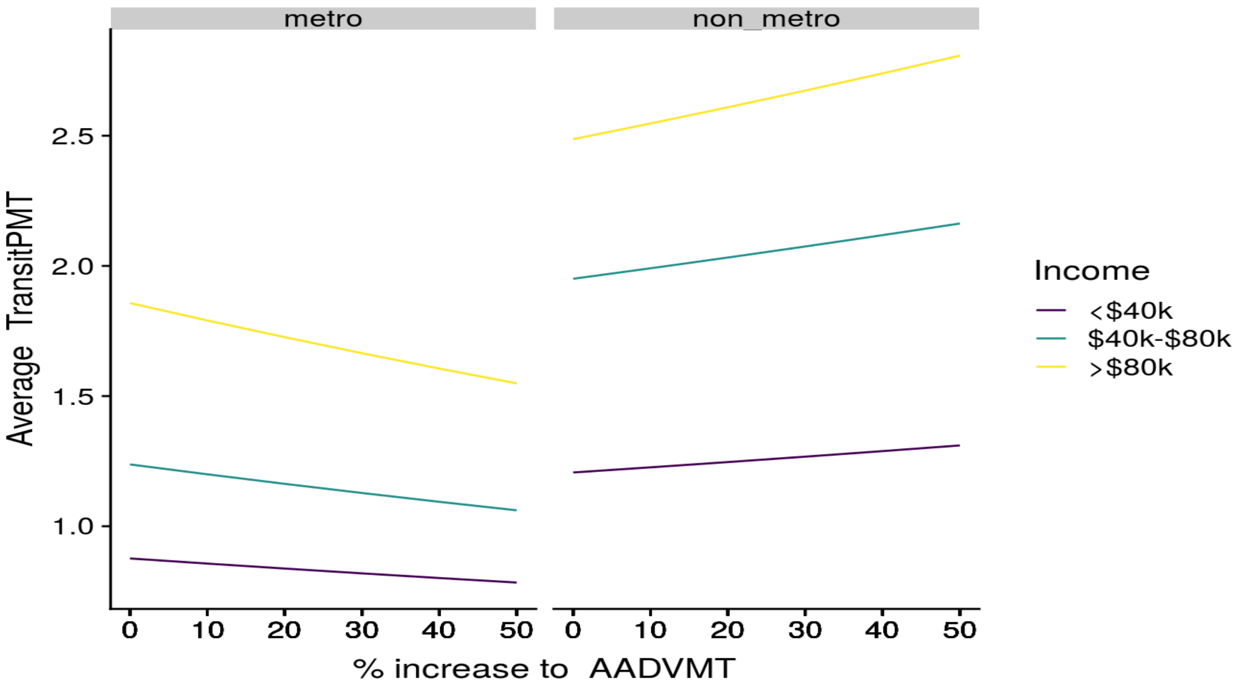
**Figure A.5 Elasticities of transit PMT with respect to D1B: overall (a), segmented by density (b), income (c) and development type (d)**


metro
non_metro
Average TransitPMT
2.0
1.8
1.6
1.4
1.2
0
10
20
30
40
50
% increase to AADVMT
overall

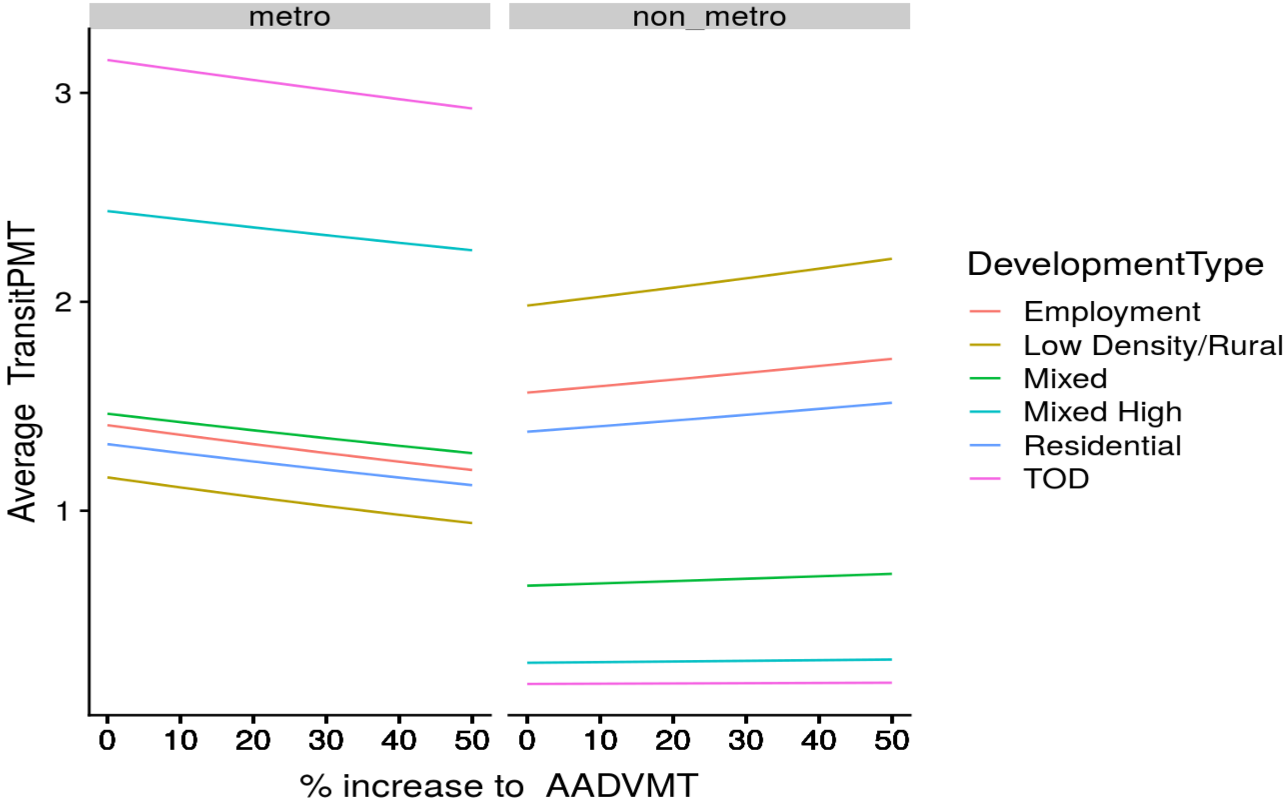
(a)


metro
non_metro
Average TransitPMT
2.0
1.5
1.0
0.5
0
10
20
30
40
50
% increase to AADVMT
population_per_sqm
<1k
1k-5k
5k-10k
>10k

(b)

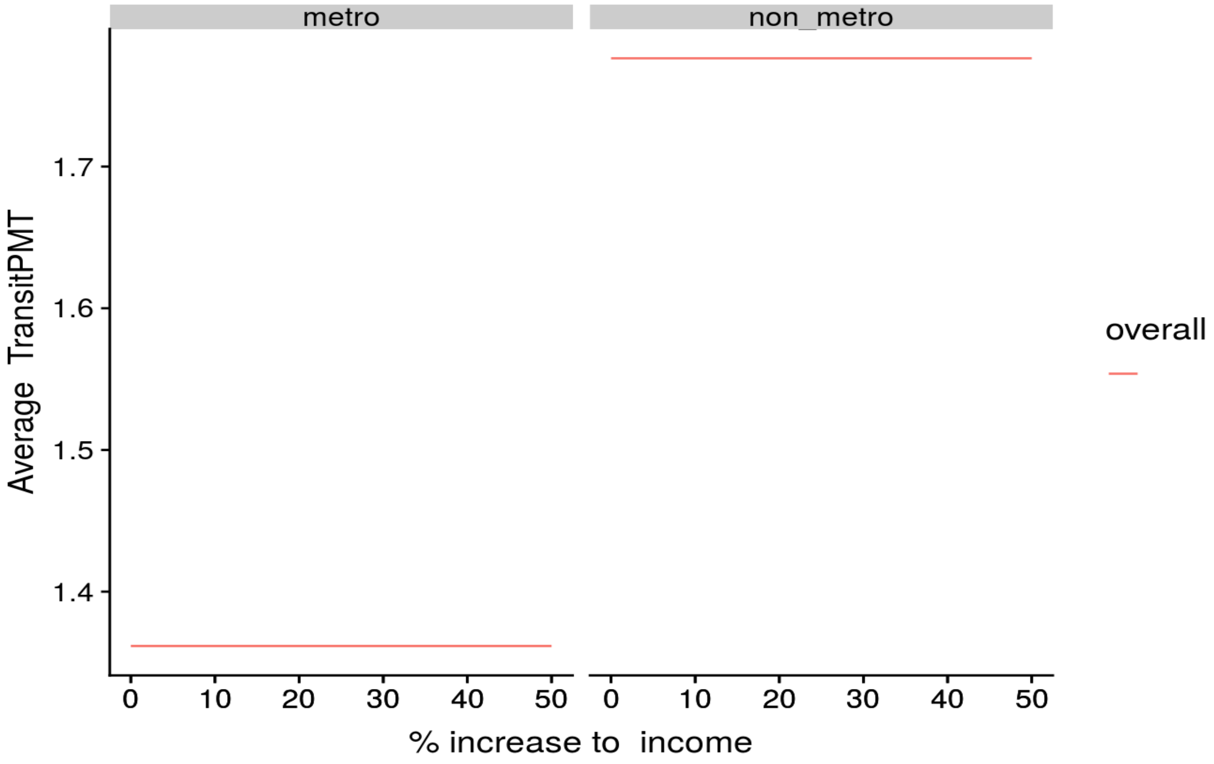


(c)

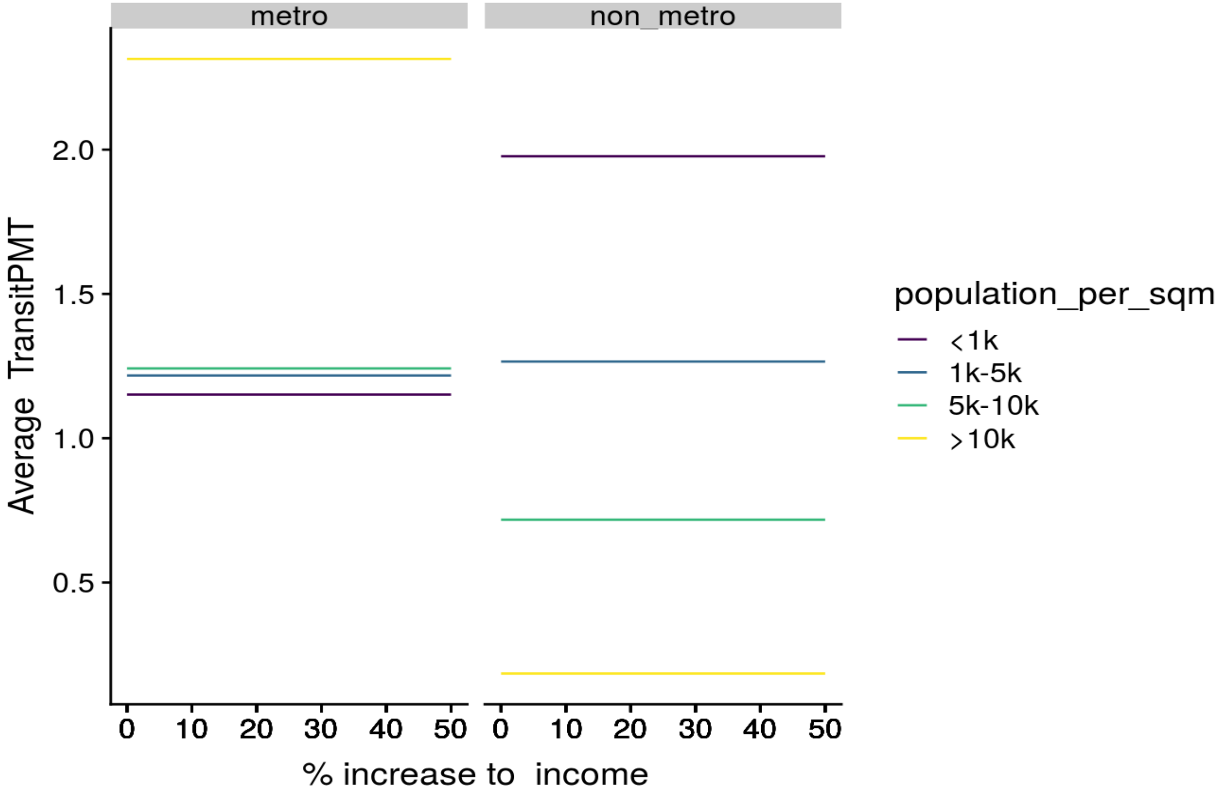


(d)

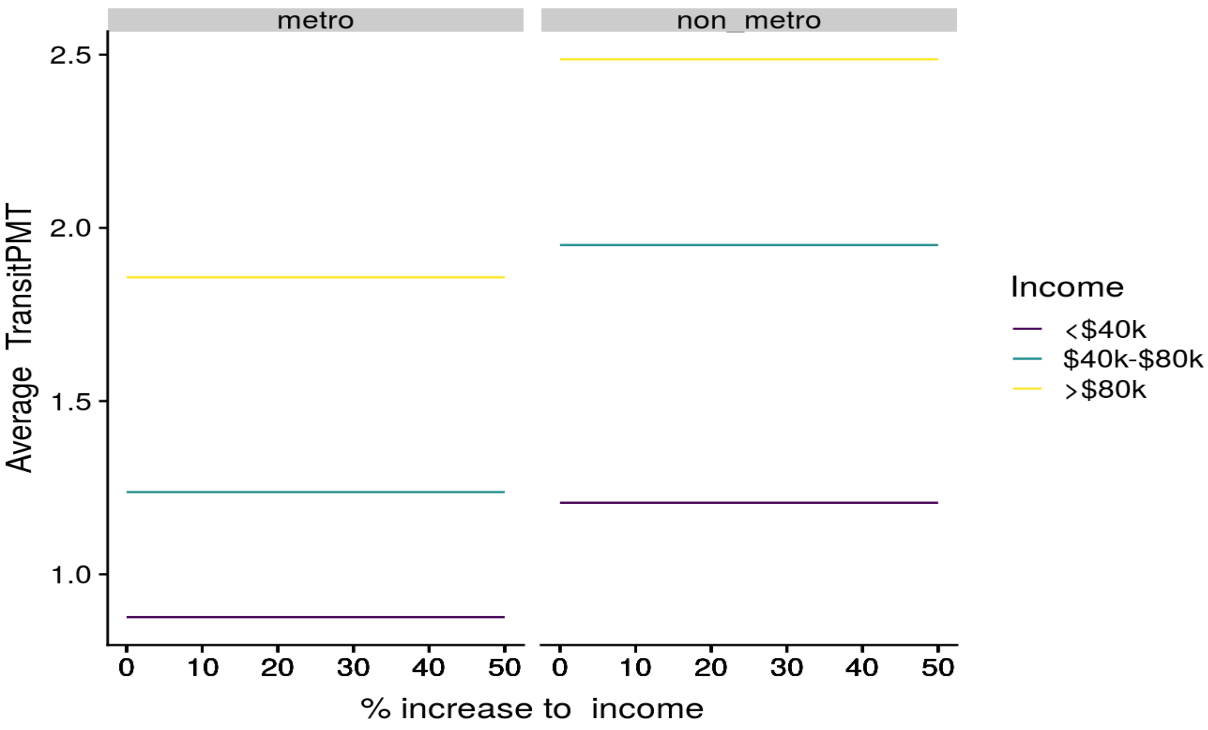
**Figure A.6 Elasticities of transit PMT with respect to AADVMT: overall (a), segmented by density (b), income (c) and development type (d)**


metro
non_metro
Average TransitPMT
1.7
1.6
1.5
1.4
0
10
20
30
40
50
% increase to income
overall

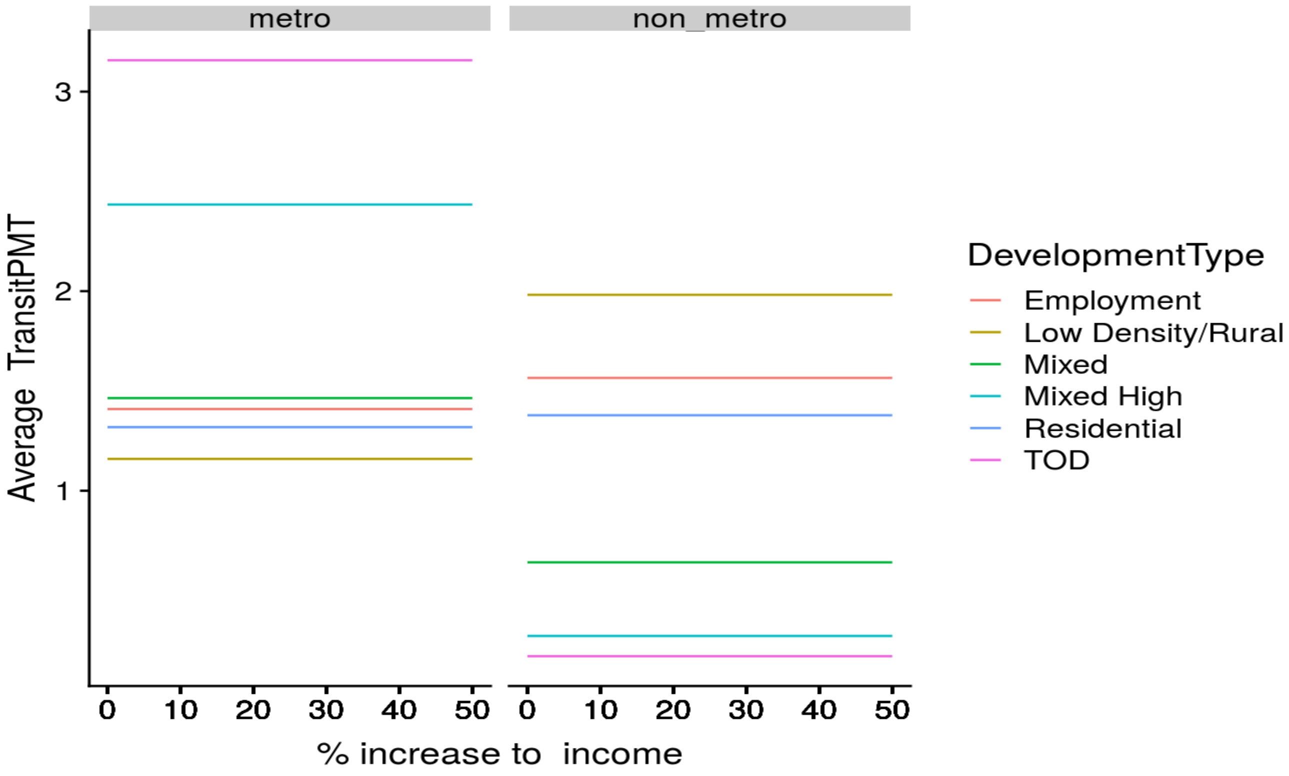
(a)


metro
non_metro
Average TransitPMT
2.0
1.5
1.0
0.5
0
10
20
30
40
50
% increase to income
population_per_sqm
<1k
1k-5k
5k-10k
>10k

(b)

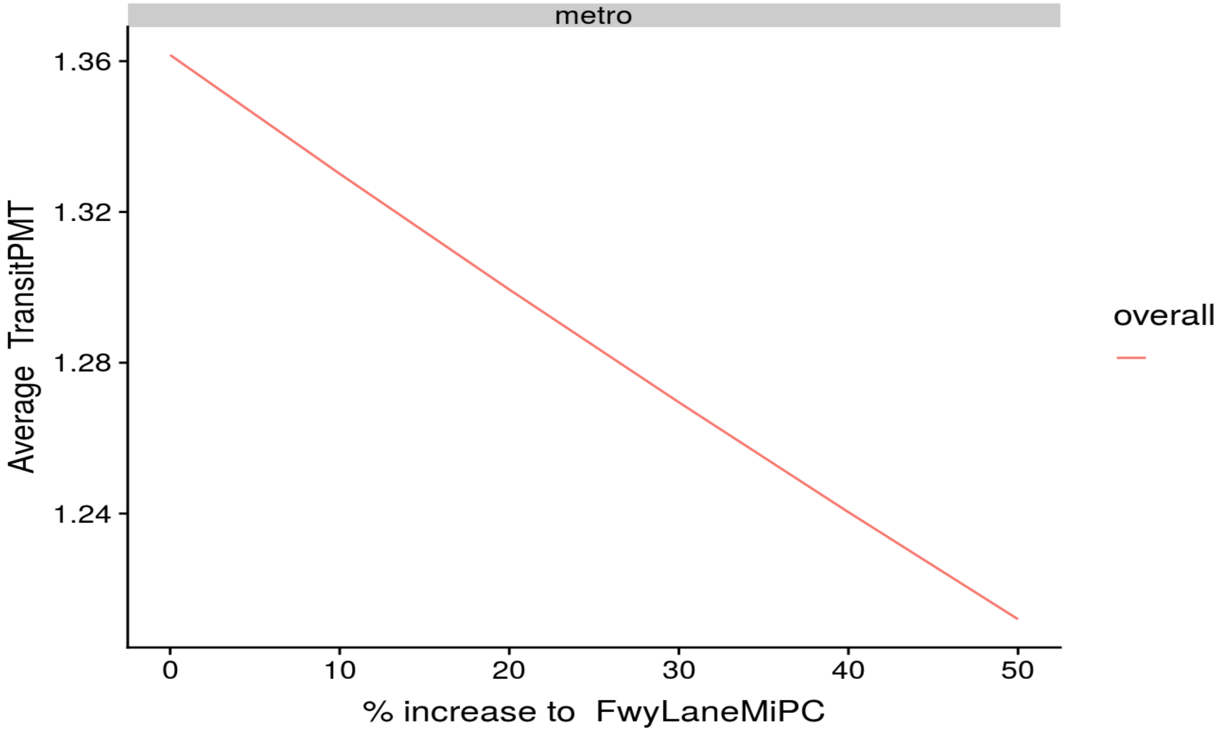


(c)

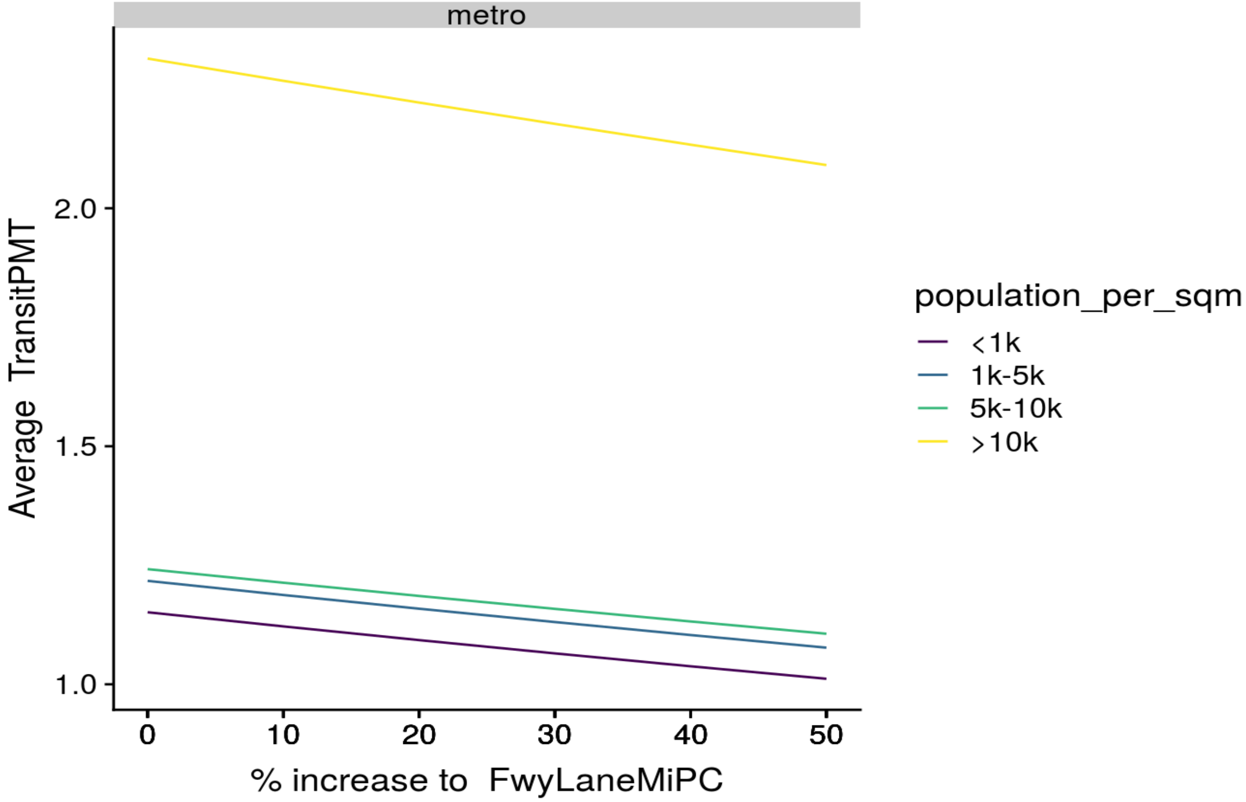


(d)

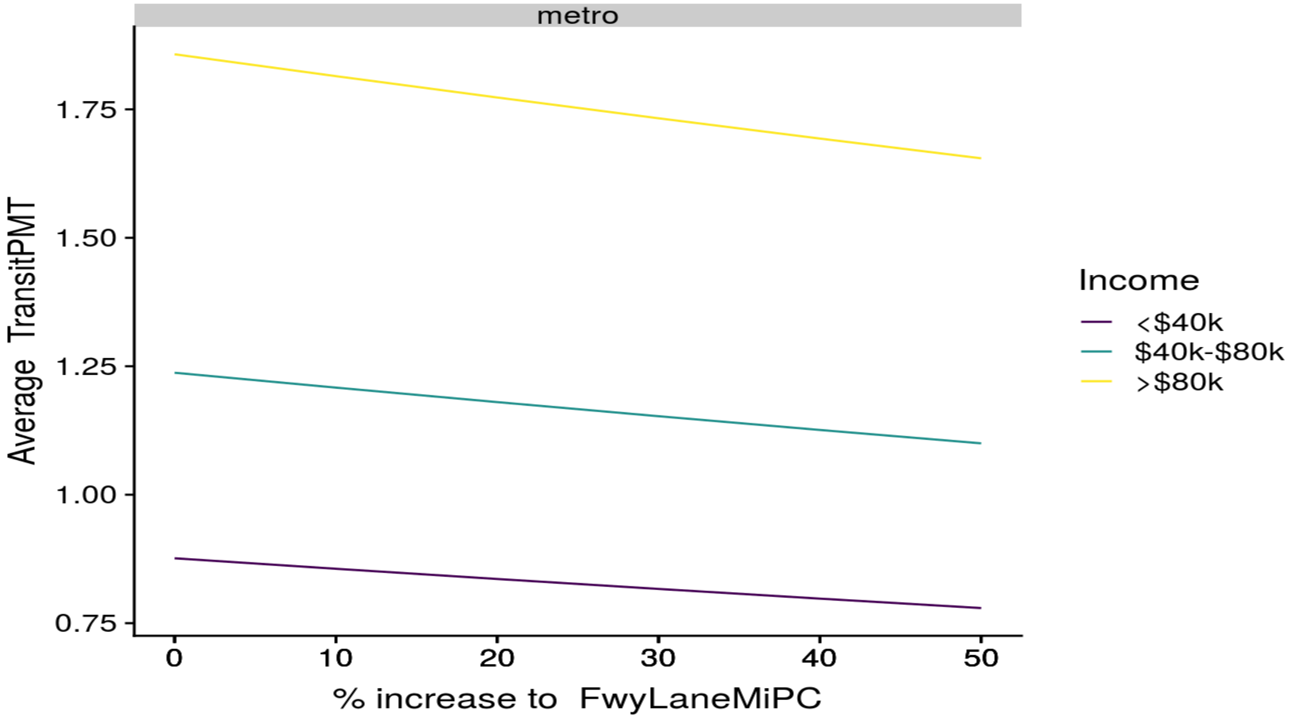
**Figure A.7 Elasticities of transit PMT with respect to household income: overall (a), segmented by density (b), income (c) and development type (d)**


metro
Average TransitPMT
1.36
1.32
1.28
1.24
0
10
20
30
40
50
% increase to FwyLaneMiPC
overall

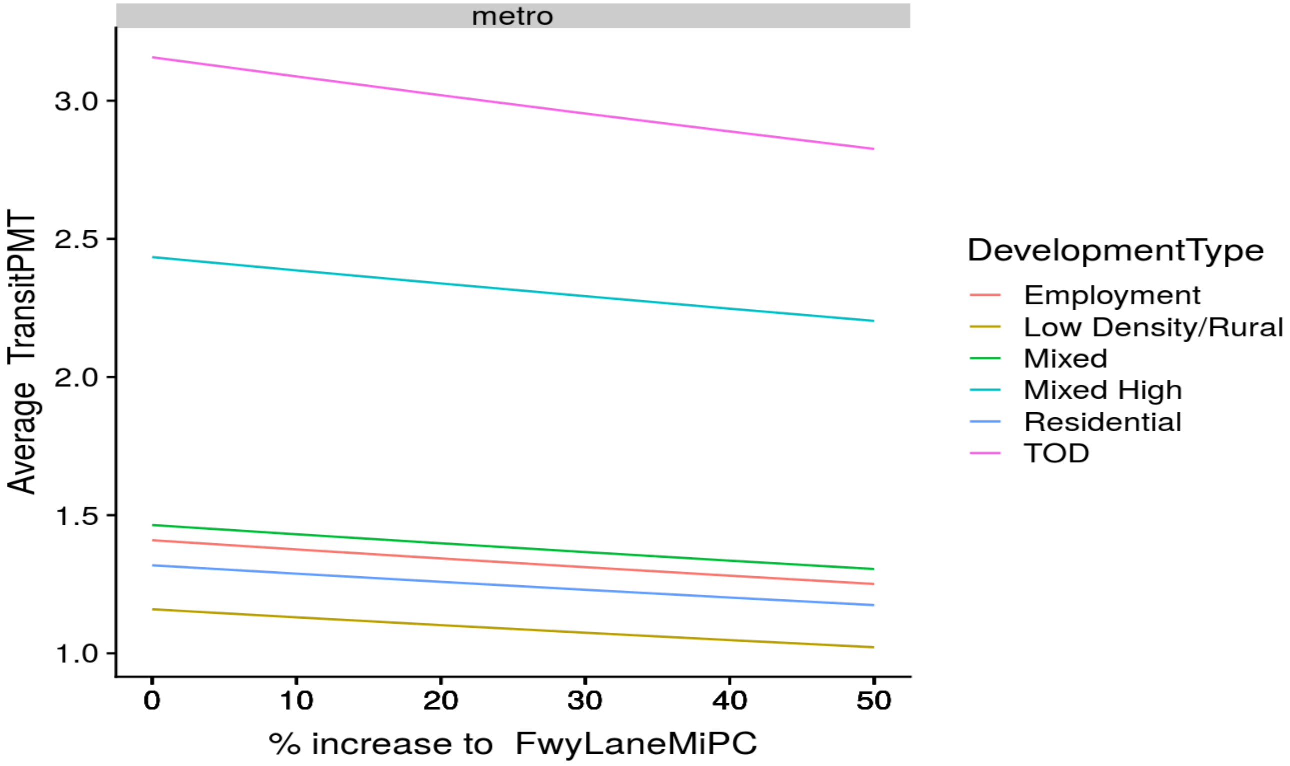
(a)


metro
Average TransitPMT
2.0
1.5
1.0
0
10
20
30
40
50
% increase to FwyLaneMiPC
population_per_sqm
<1k
1k-5k
5k-10k
>10k

(b)

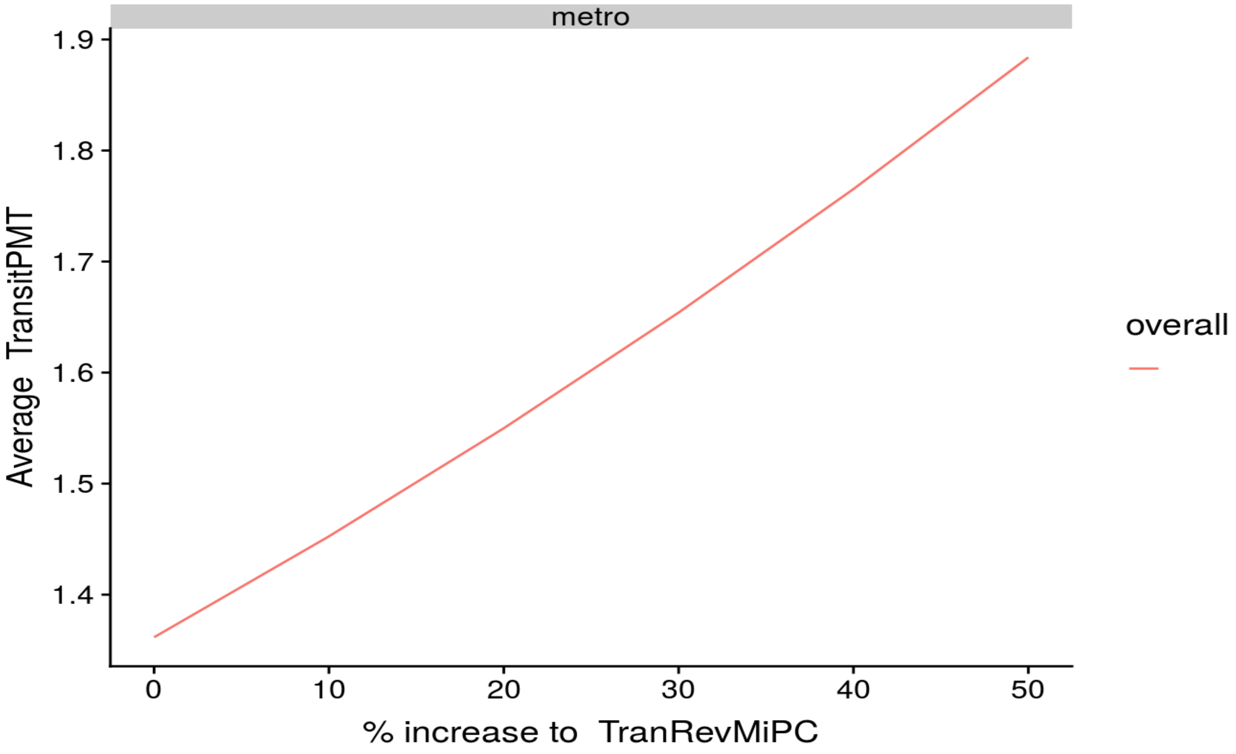


(c)

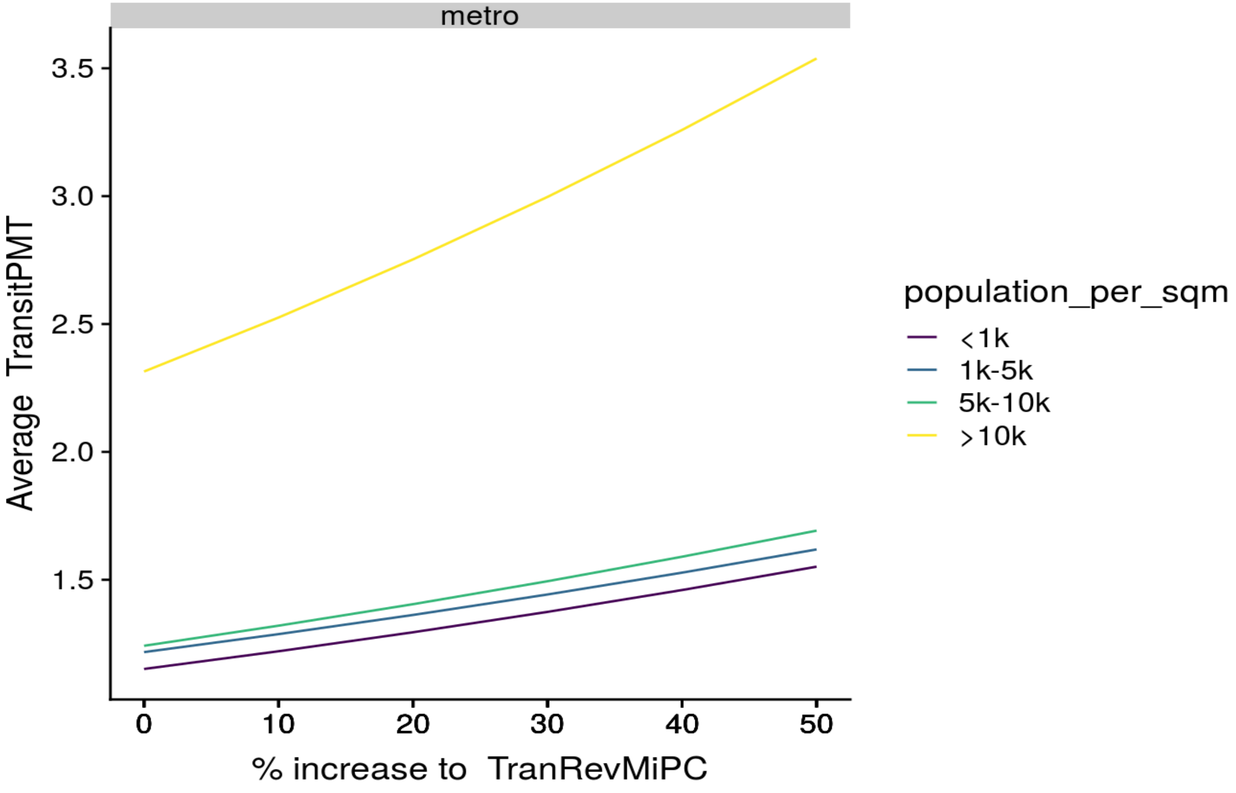


(d)

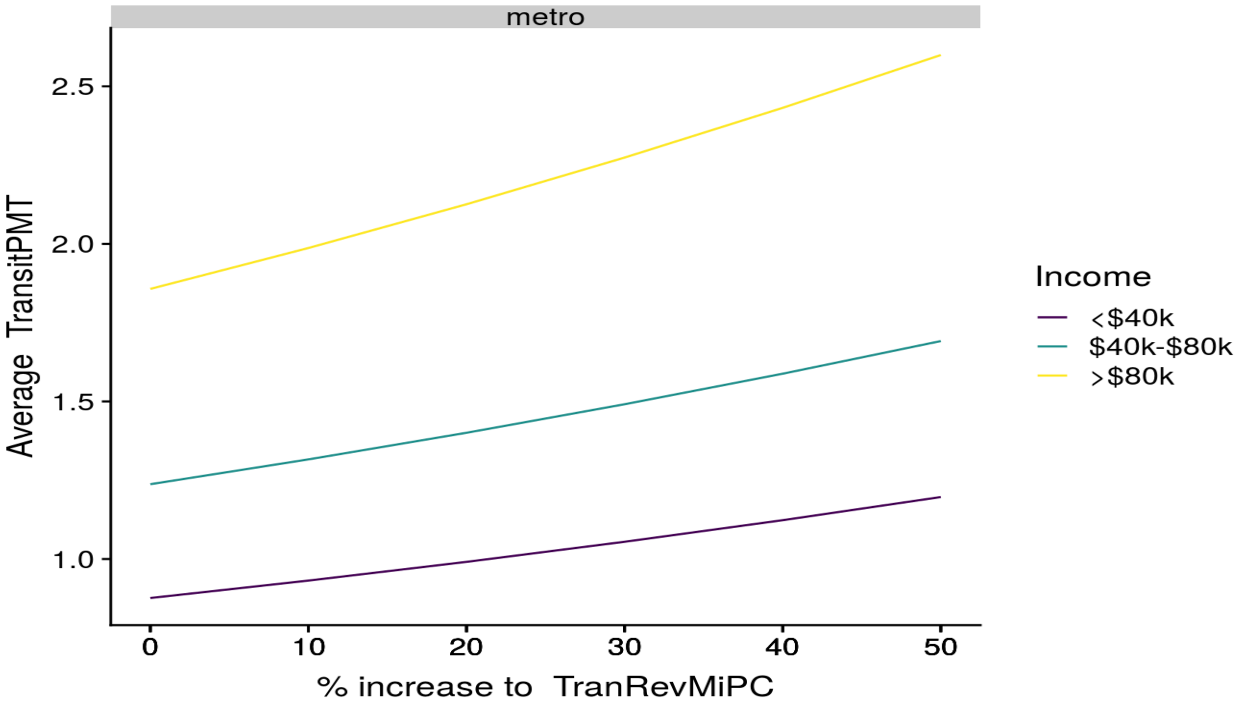
**FigureA.8 Elasticities of transit PMT with respect to freeway lane mile per capita: overall (a), segmented by density (b), income (c) and development type (d)**


metro
Average TransitPMT
1.9
1.8
1.7
1.6
1.5
1.4
0
10
20
30
40
50
% increase to TranRevMiPC
overall

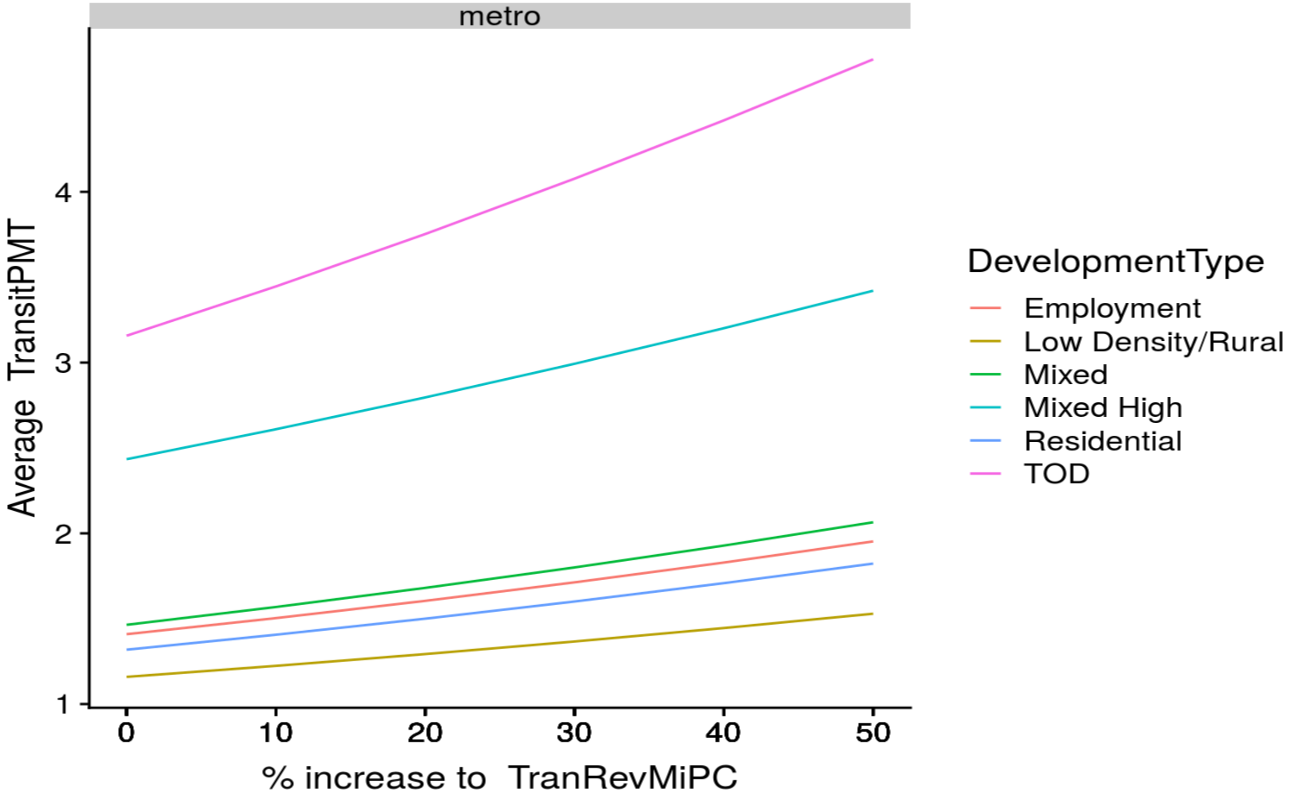
(a)


metro
Average TransitPMT
3.5
3.0
2.5
2.0
1.5
0
10
20
30
40
50
% increase to TranRevMiPC
population_per_sqm
<1k
1k-5k
5k-10k
>10k

(b)

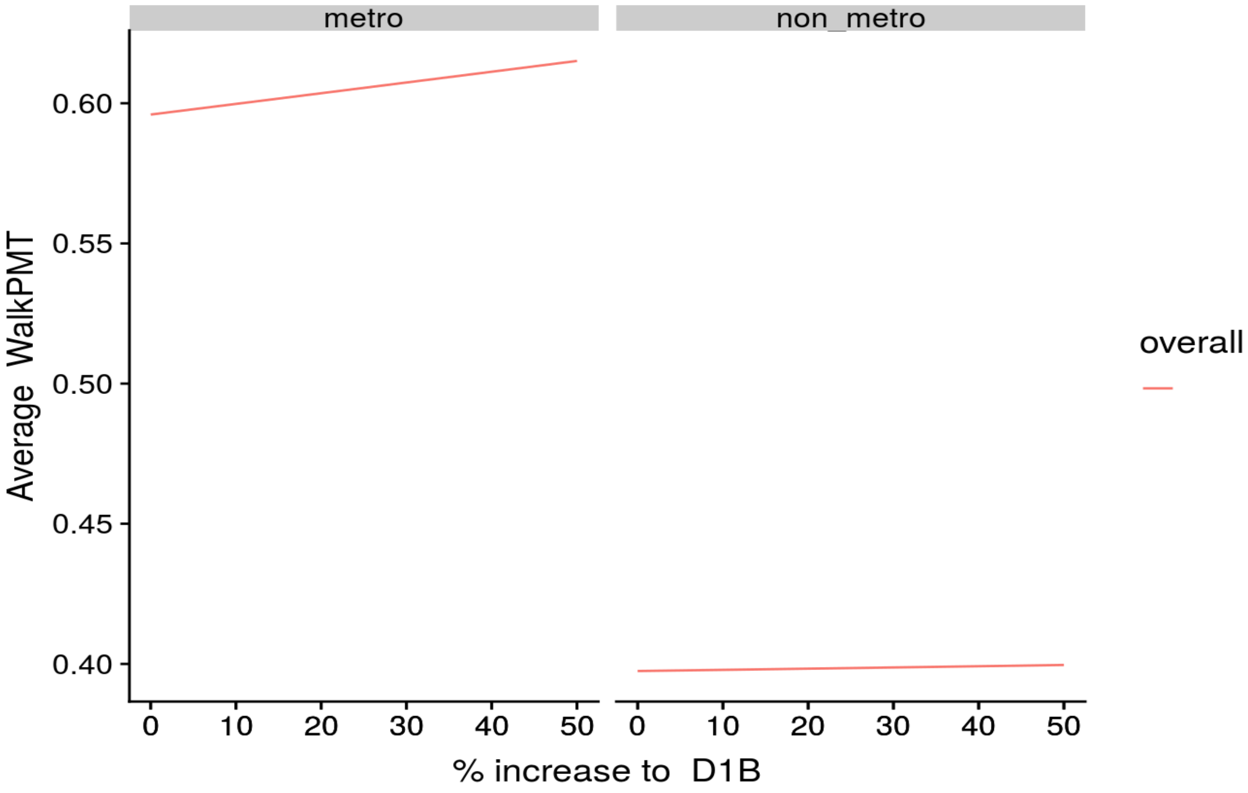


(c)

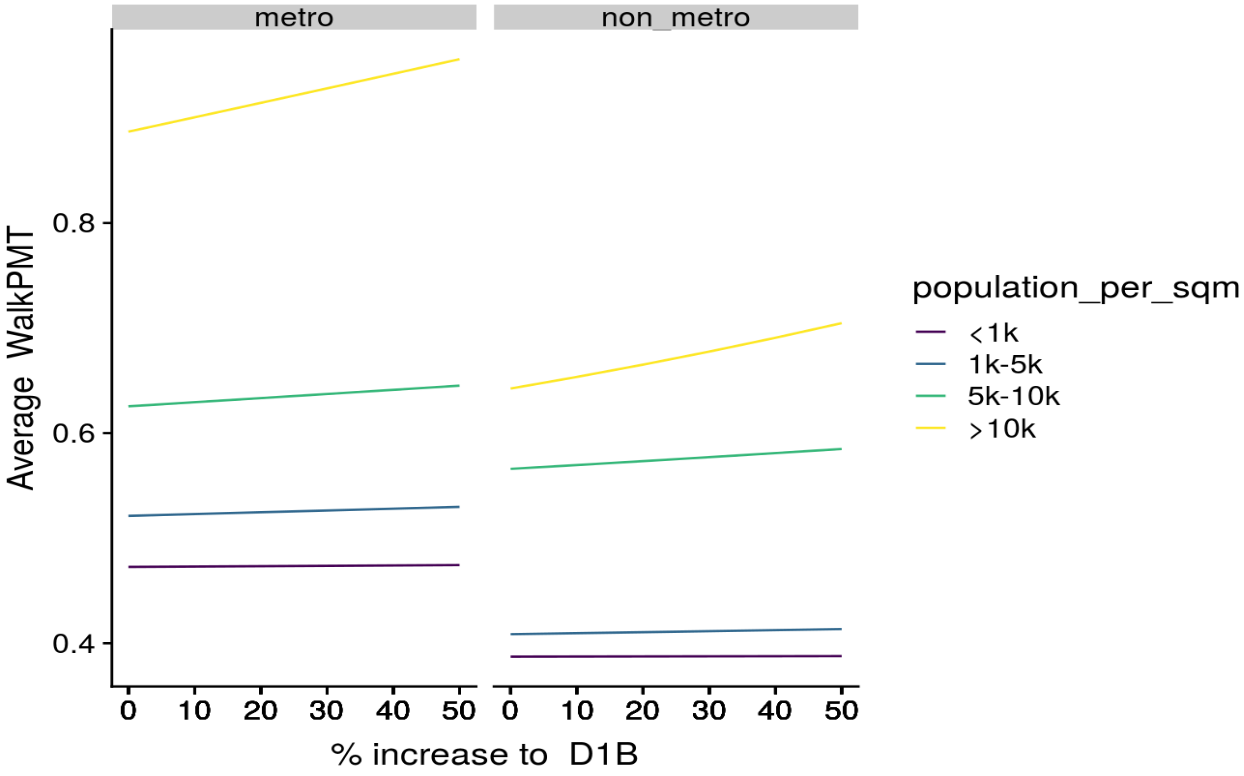


(d)

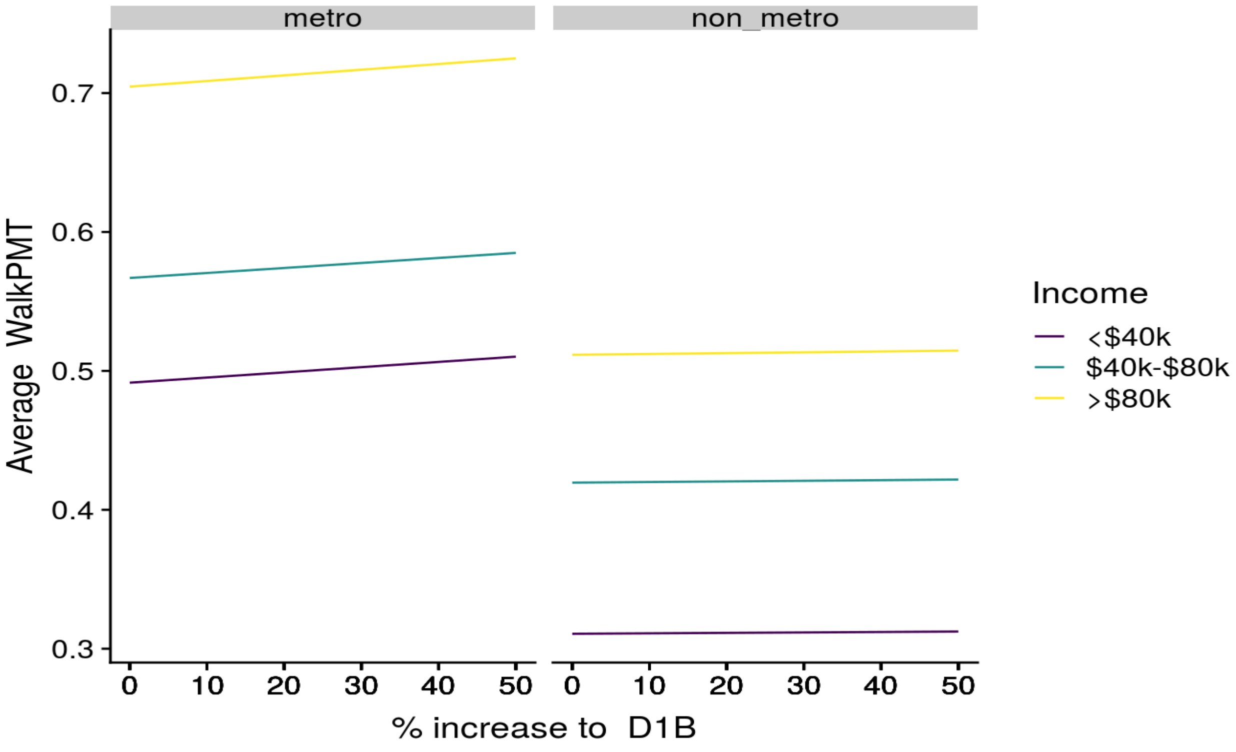
**Figure A.9 Elasticities of transit PMT with respect to transit revenue miles per capita: overall (a), segmented by density (b), income (c) and development type (d)**


metro
non_metro
Average WalkPMT
0.60
0.55
0.50
0.45
0.40
0
10
20
30
40
50
% increase to D1B
overall

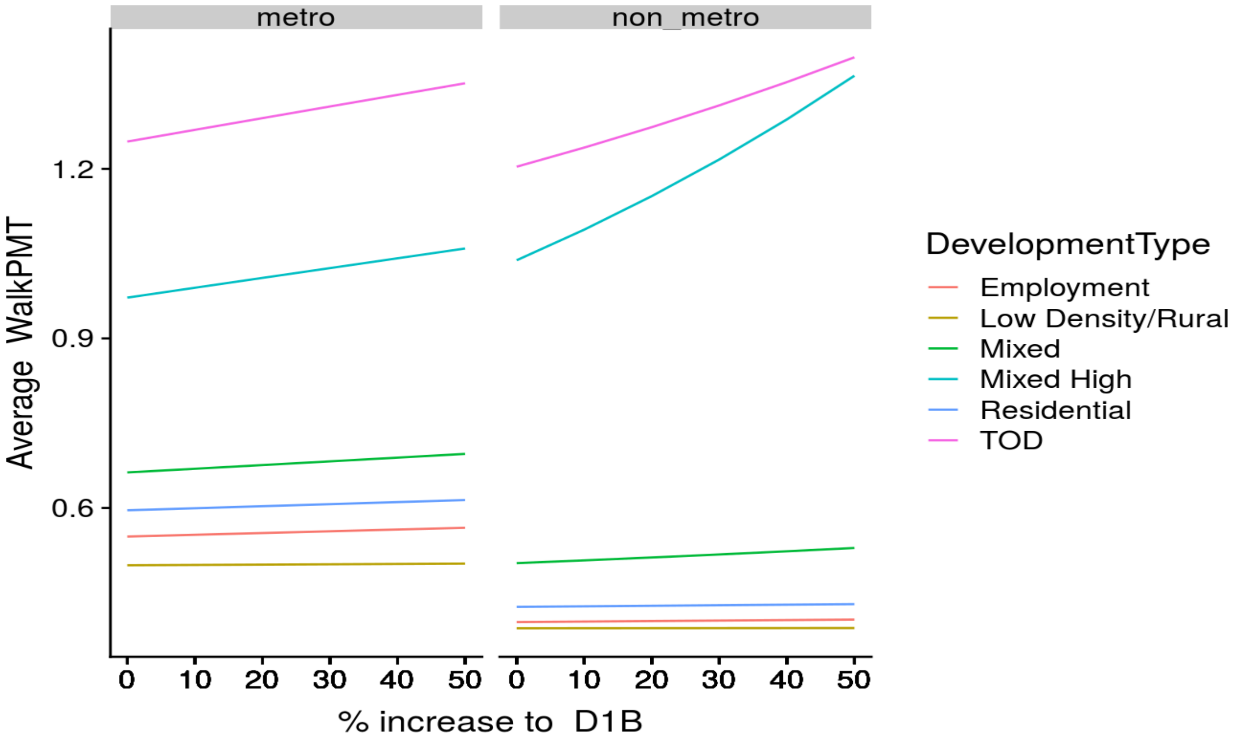
(a)


metro
non_metro
Average WalkPMT
0.8
0.6
0.4
0
10
20
30
40
50
% increase to D1B
population_per_sqm
<1k
1k-5k
5k-10k
>10k

(b)

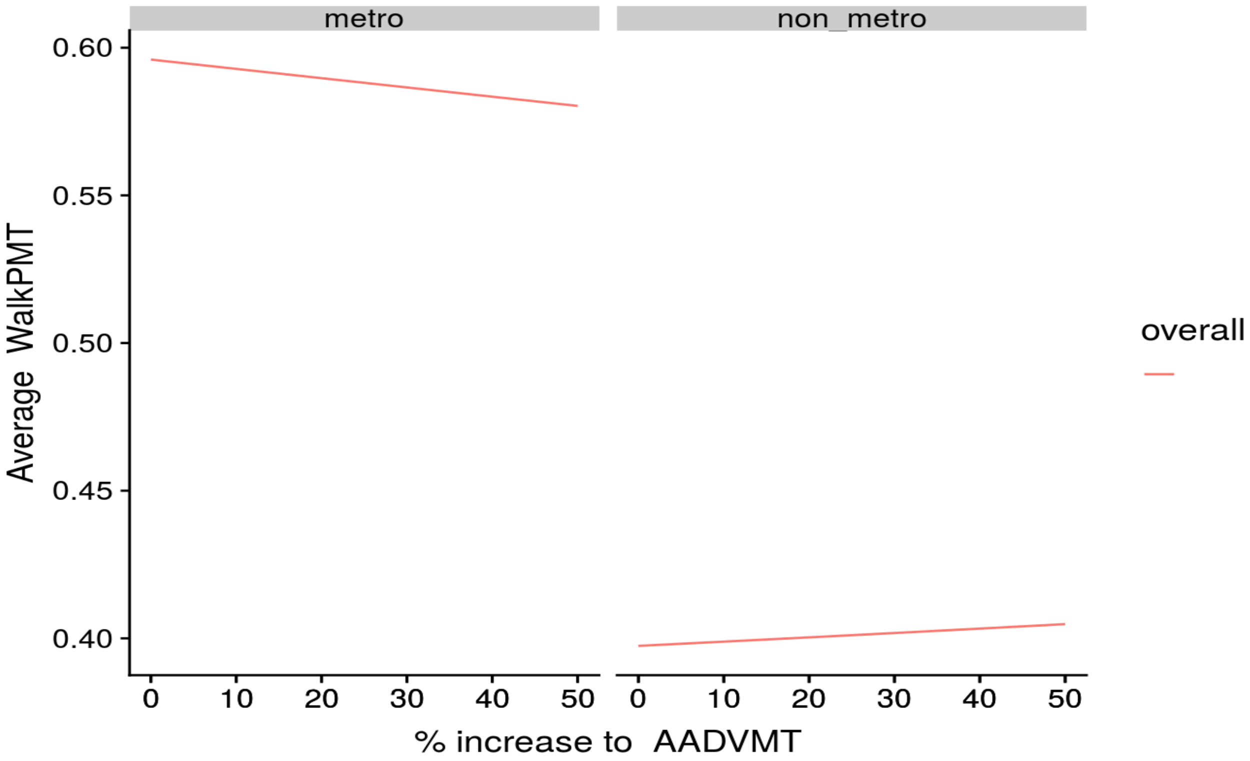


(c)

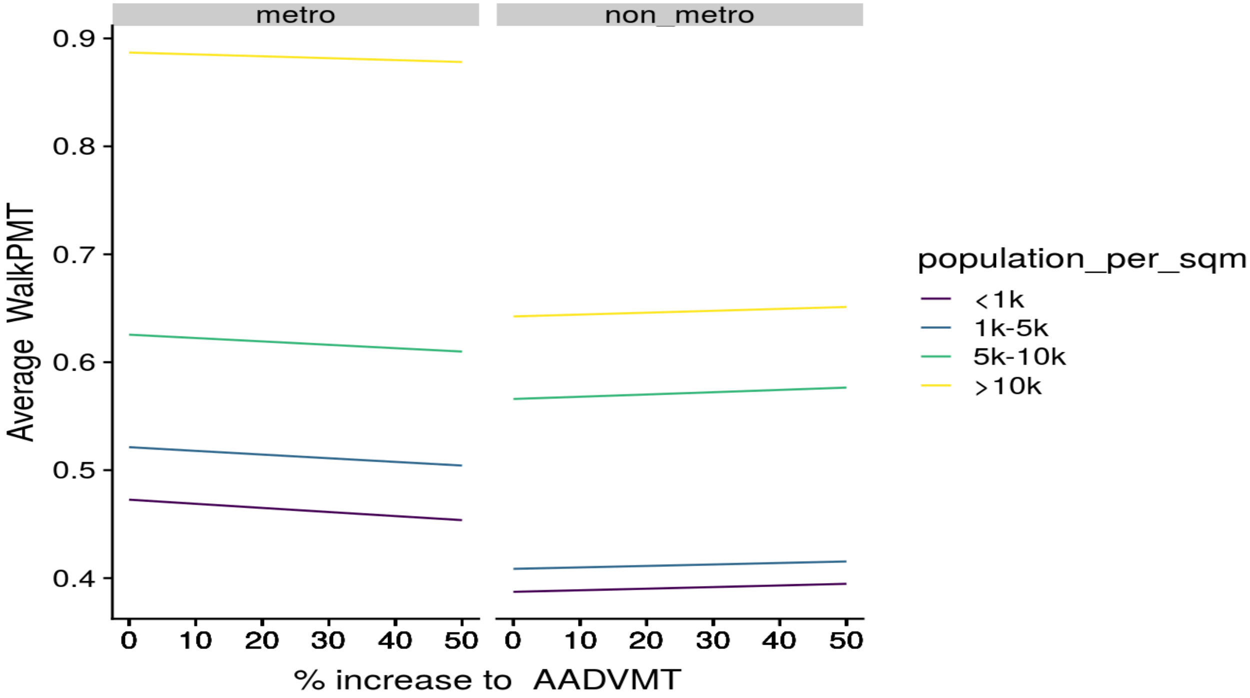


(d)

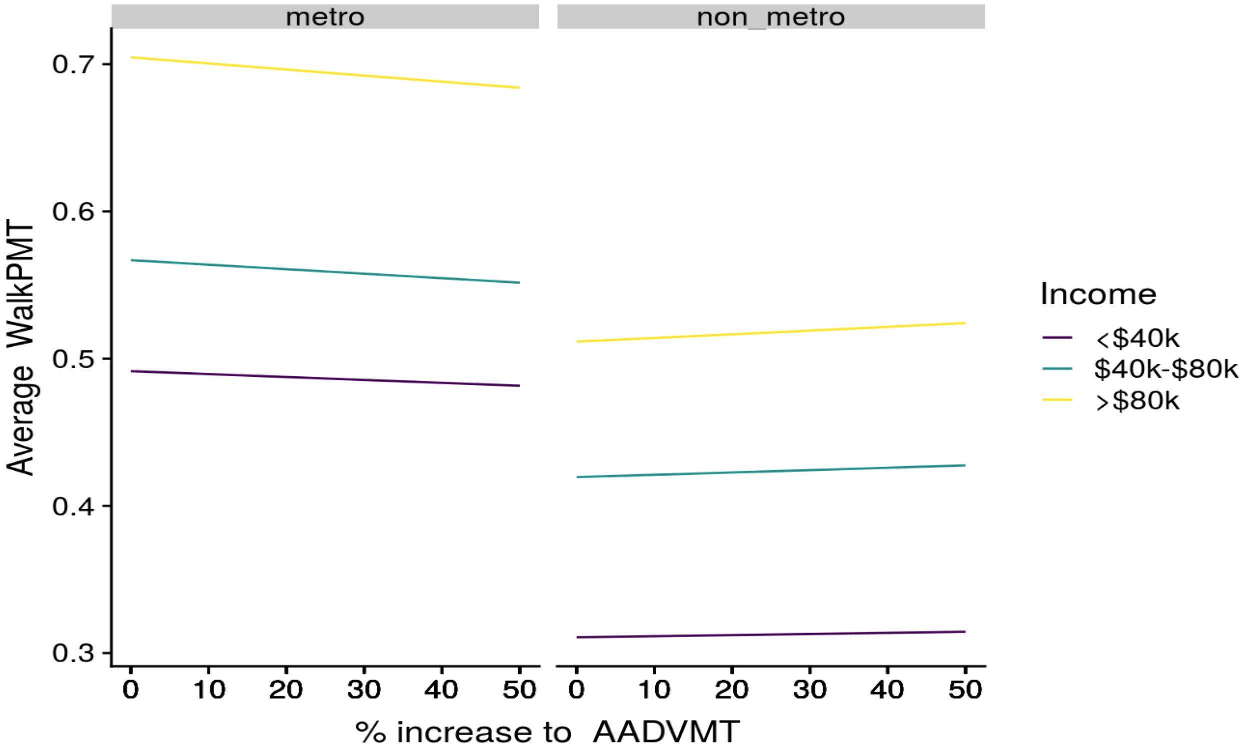
**Figure A.10 Elasticities of walking PMT with respect to D1B: overall (a), segmented by density (b), income (c) and development type (d)**


metro
non_metro
0.60
0.55
0.50
0.45
0.40
Average WalkPMT
0
10
20
30
40
50
% increase to AADVMT
overall

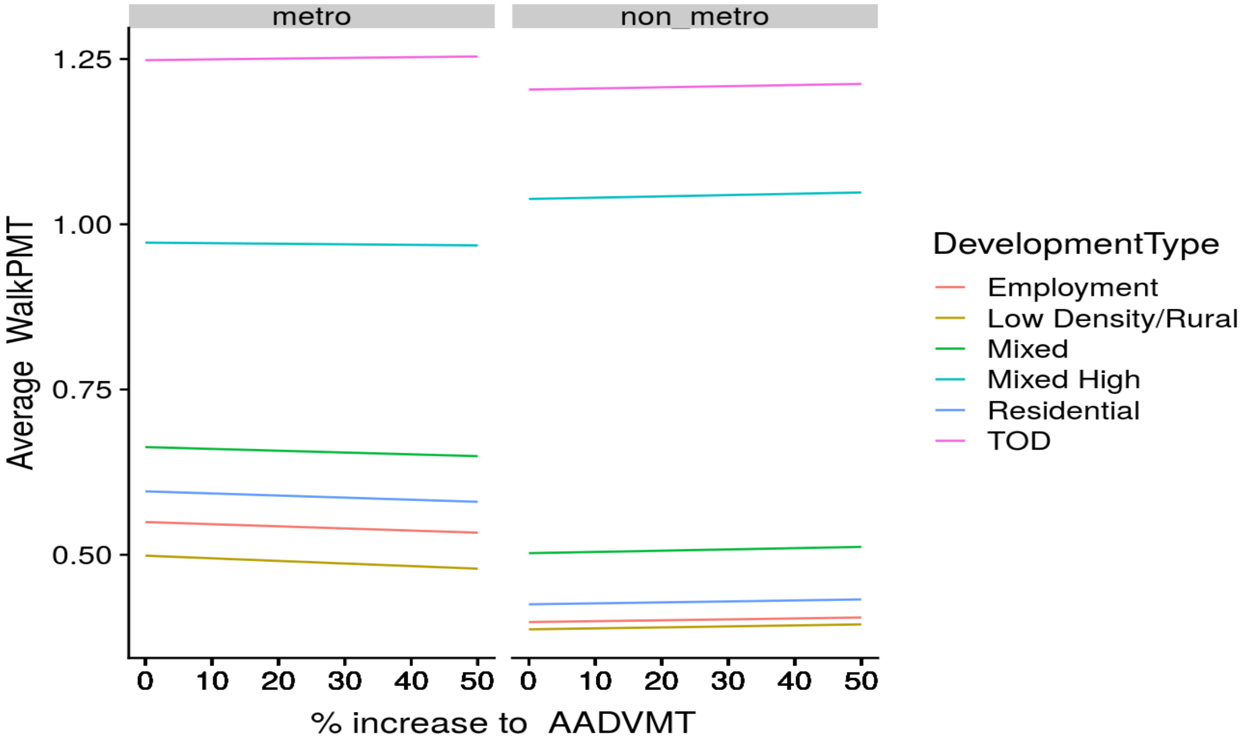
(a)


metro
non_metro
0.9
0.8
0.7
0.6
0.5
0.4
Average WalkPMT
0
10
20
30
40
50
% increase to AADVMT
population_per_sqm
<1k
1k-5k
5k-10k
>10k

(b)

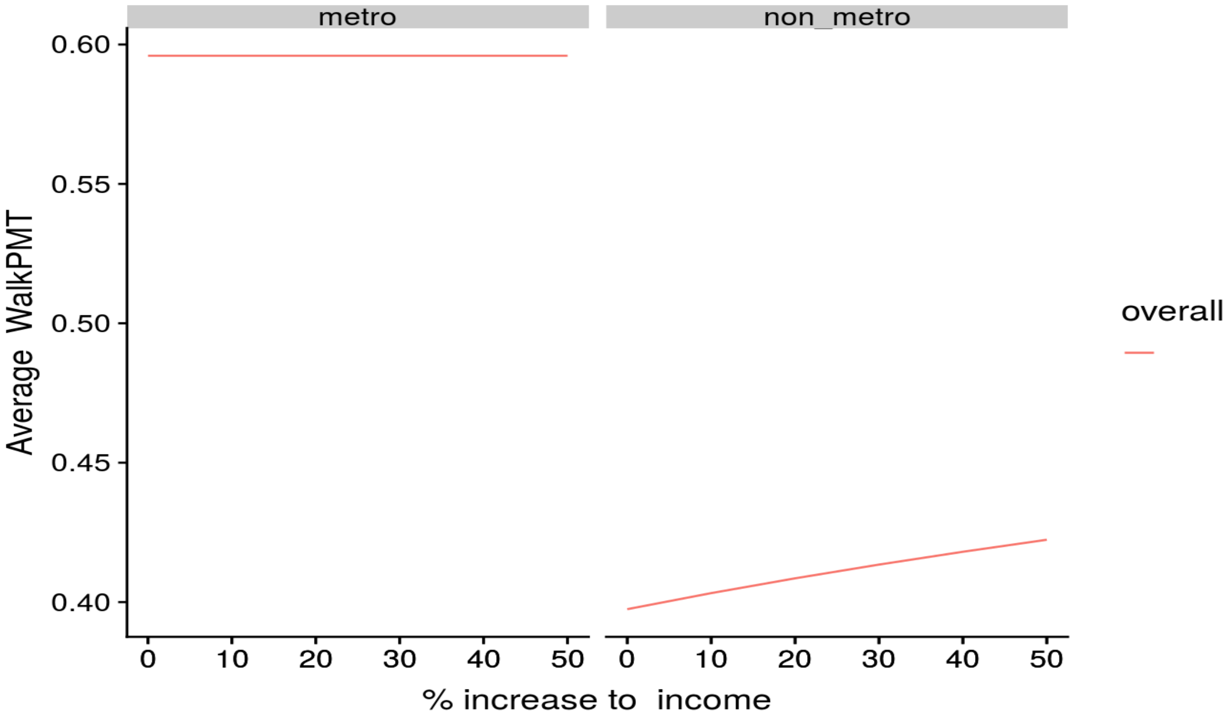


(c)

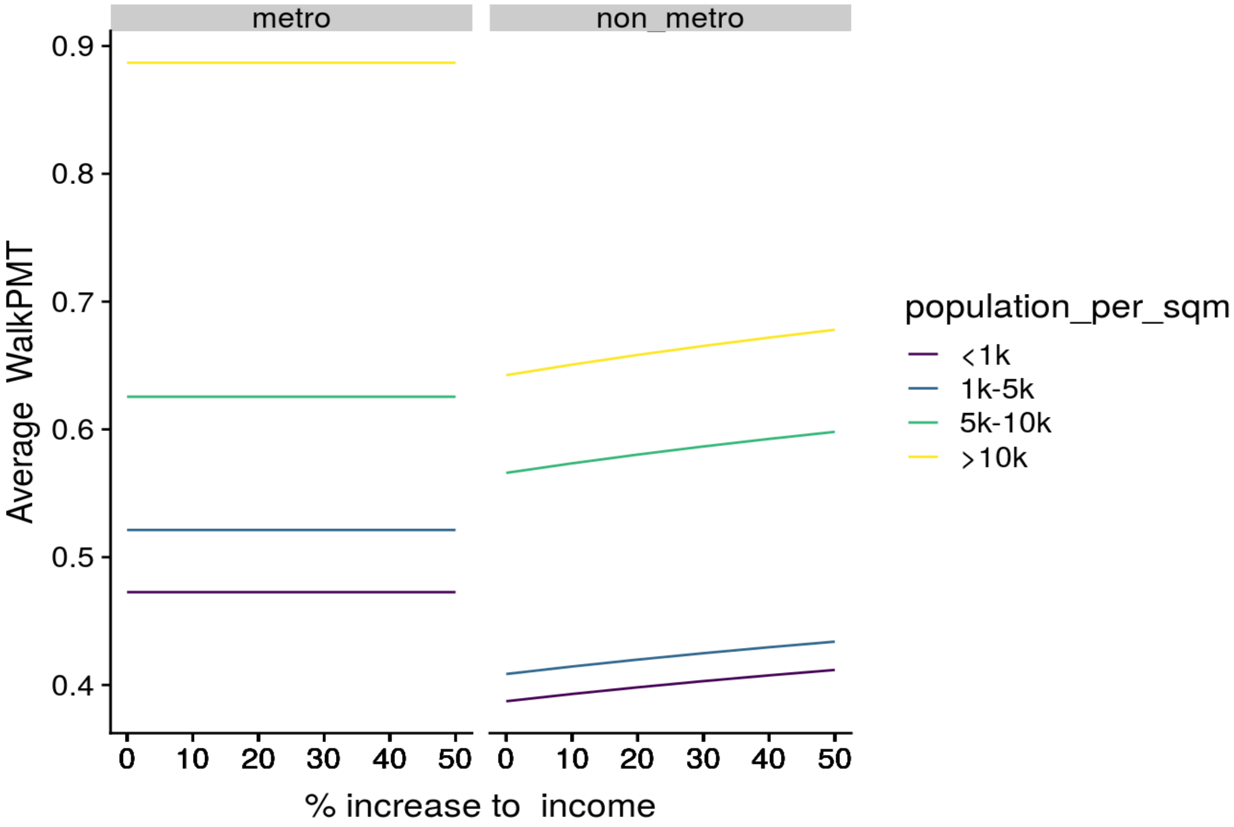


(d)

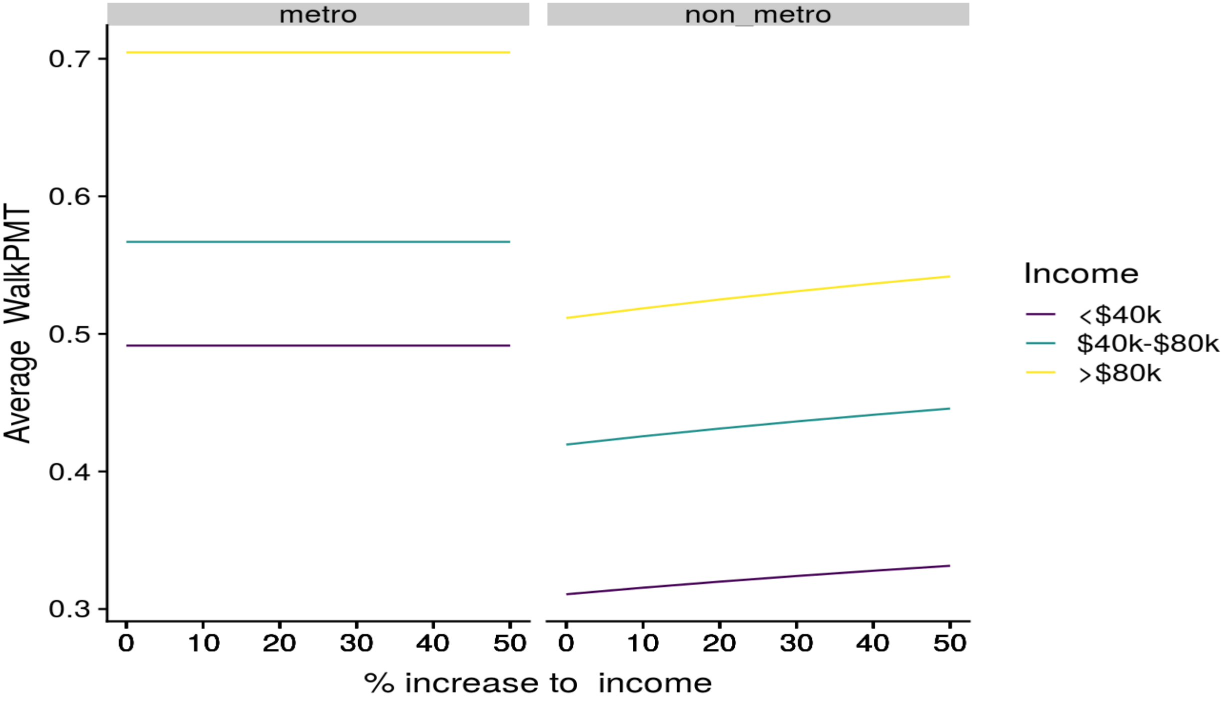
**Figure A.11 Elasticities of walking PMT with respect to AADVMT: overall (a), segmented by density (b), income (c) and development type (d)**


metro
non_metro
0.60
0.55
0.50
0.45
0.40
Average WalkPMT
0
10
20
30
40
50
% increase to income
overall

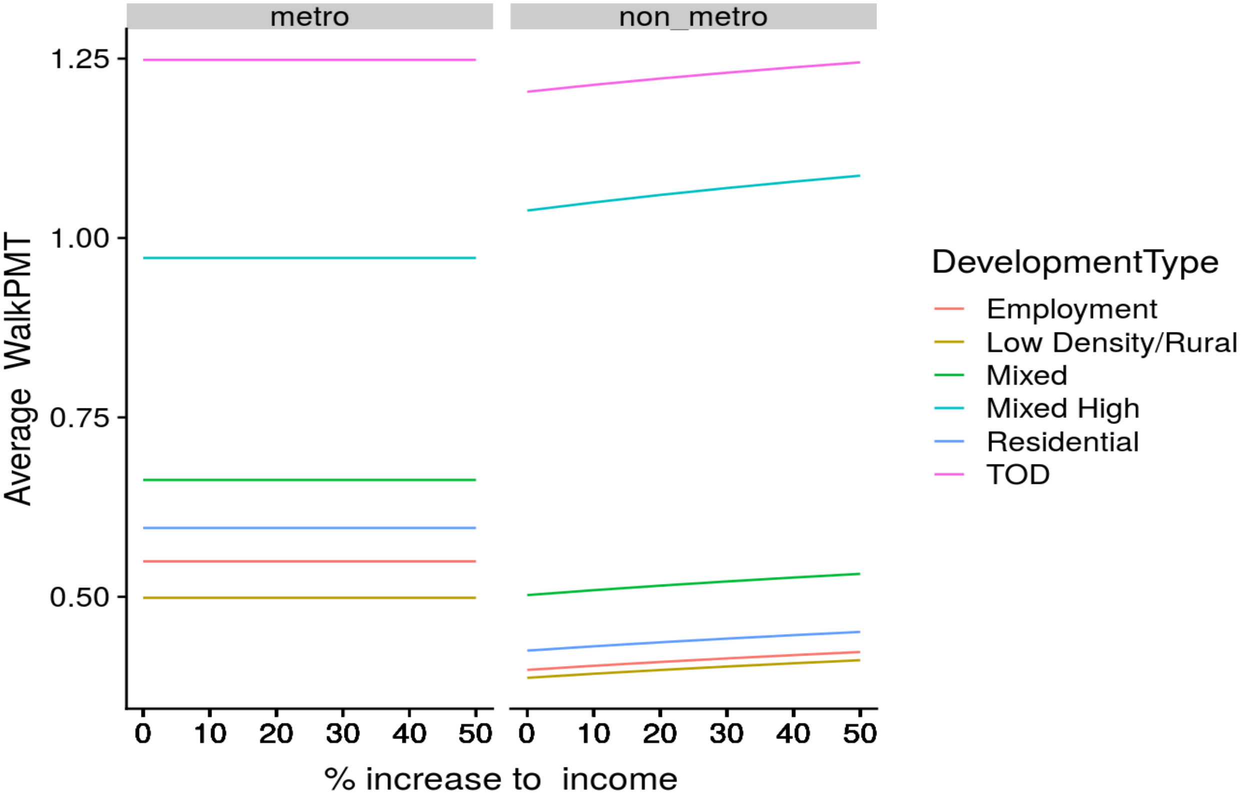
(a)


metro
non_metro
0.9
0.8
0.7
0.6
0.5
0.4
Average WalkPMT
0
10
20
30
40
50
% increase to income
population_per_sqm
<1k
1k-5k
5k-10k
>10k

(b)

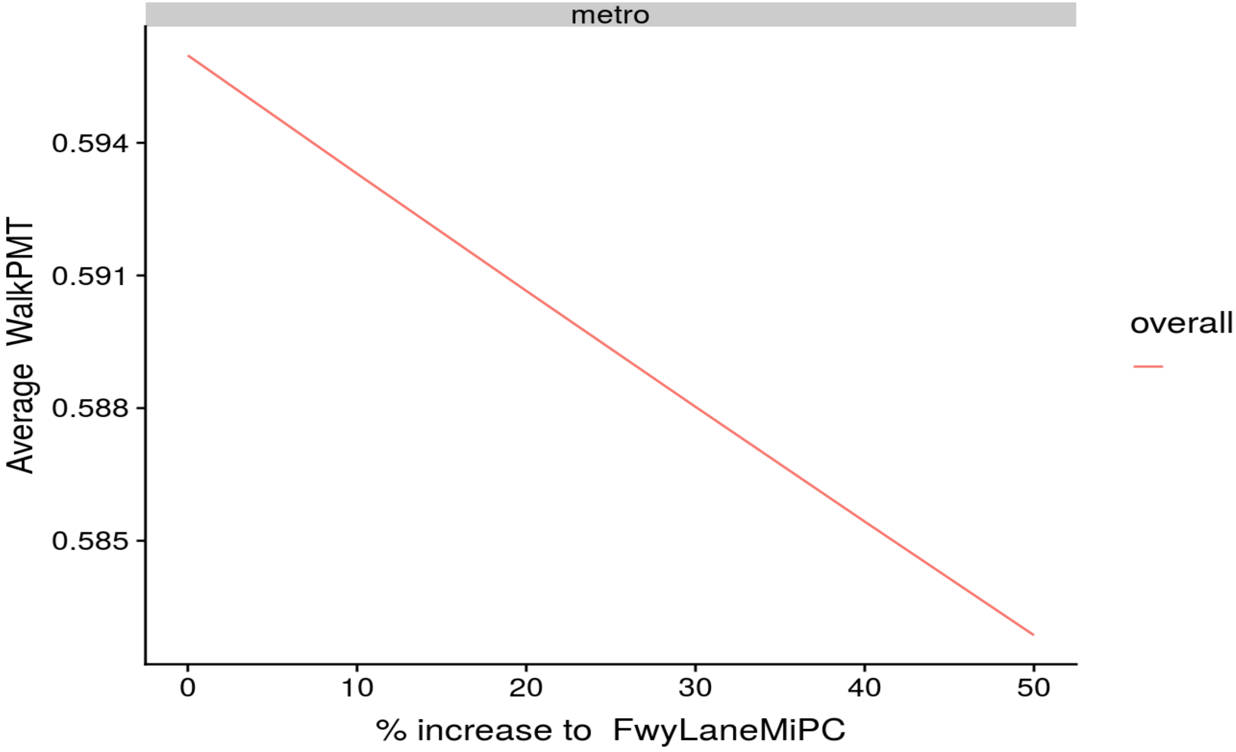


(c)

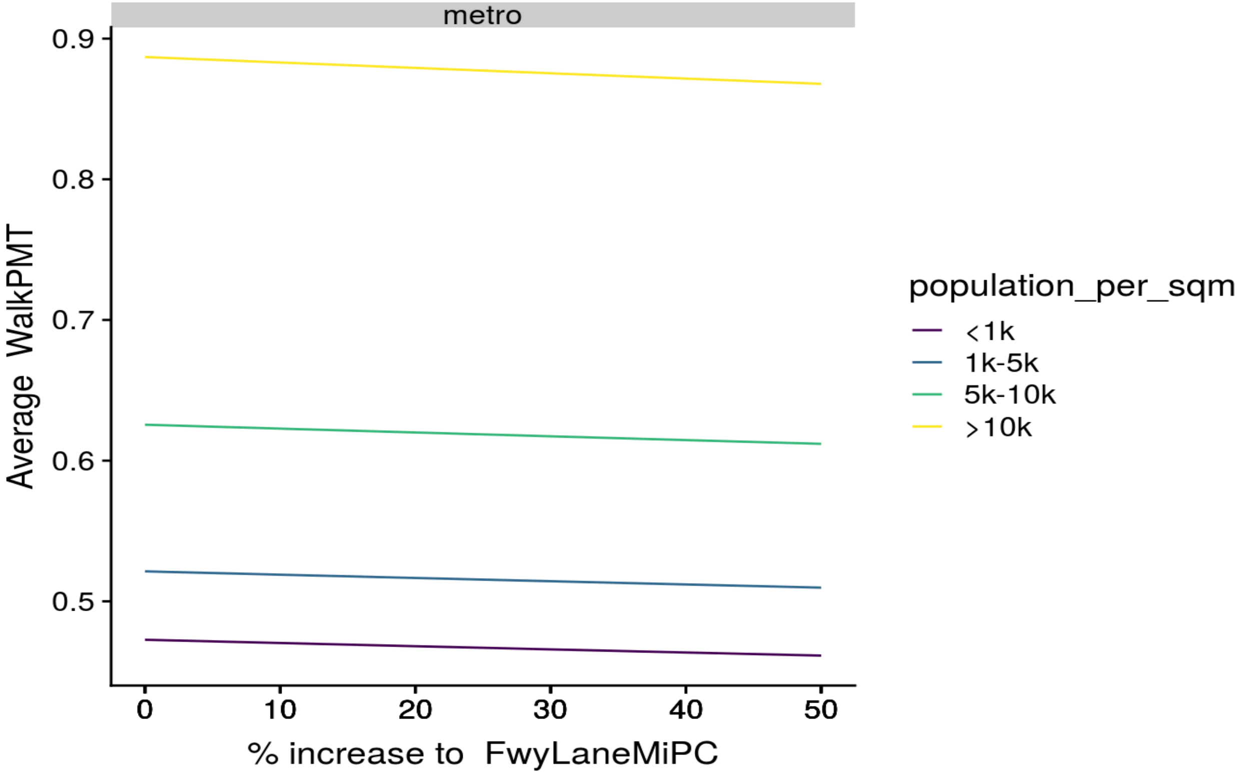


(d)

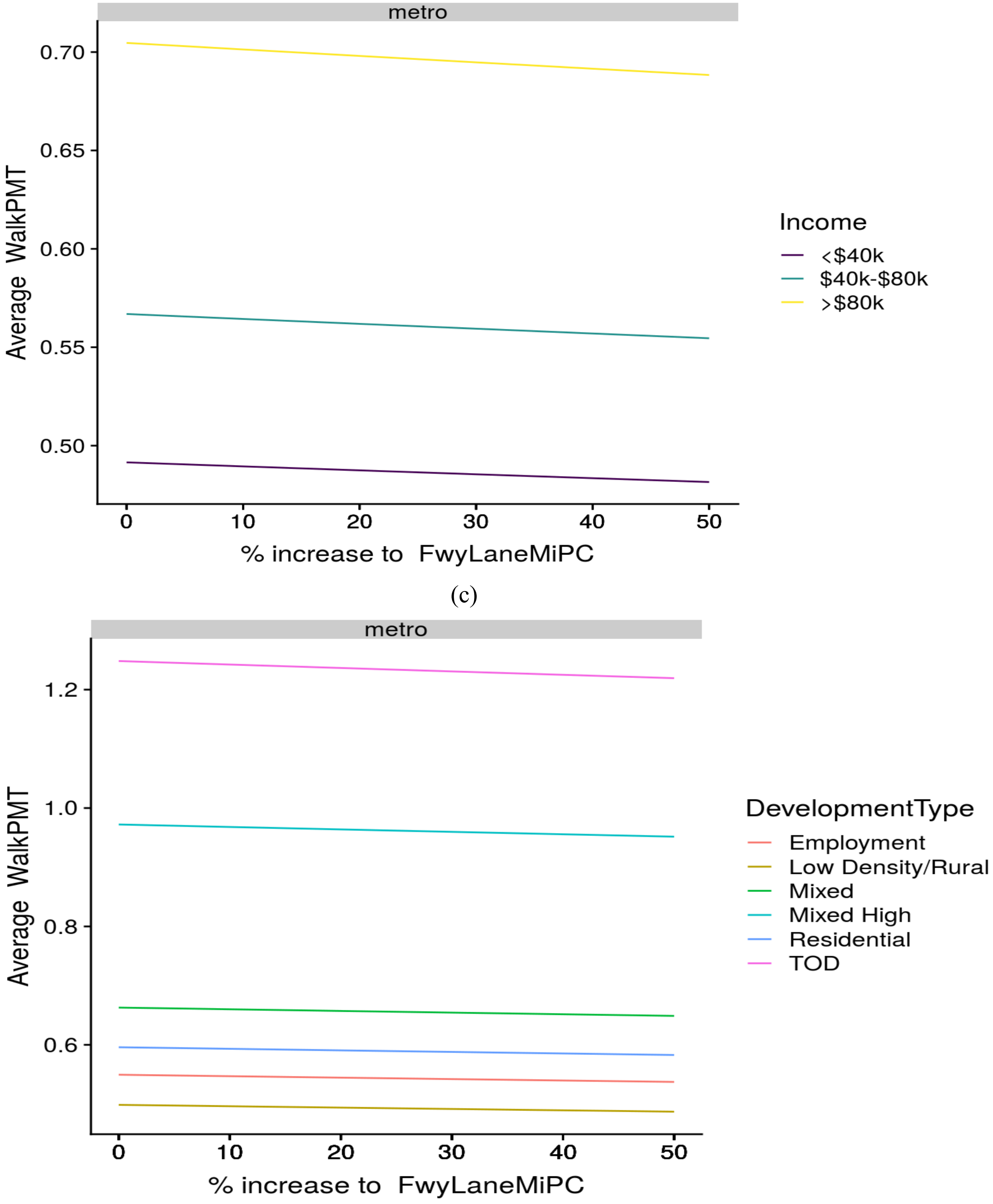
**Figure A.12 Elasticities of walking PMT with respect to household income: overall (a), segmented by density (b), income (c) and development type (d)**


metro
Average WalkPMT
0.594
0.591
0.588
0.585
0
10
20
30
40
50
% increase to FwyLaneMiPC
overall

(a)


metro
Average WalkPMT
0.9
0.8
0.7
0.6
0.5
0
10
20
30
40
50
% increase to FwyLaneMiPC
population_per_sqm
<1k
1k-5k
5k-10k
>10k

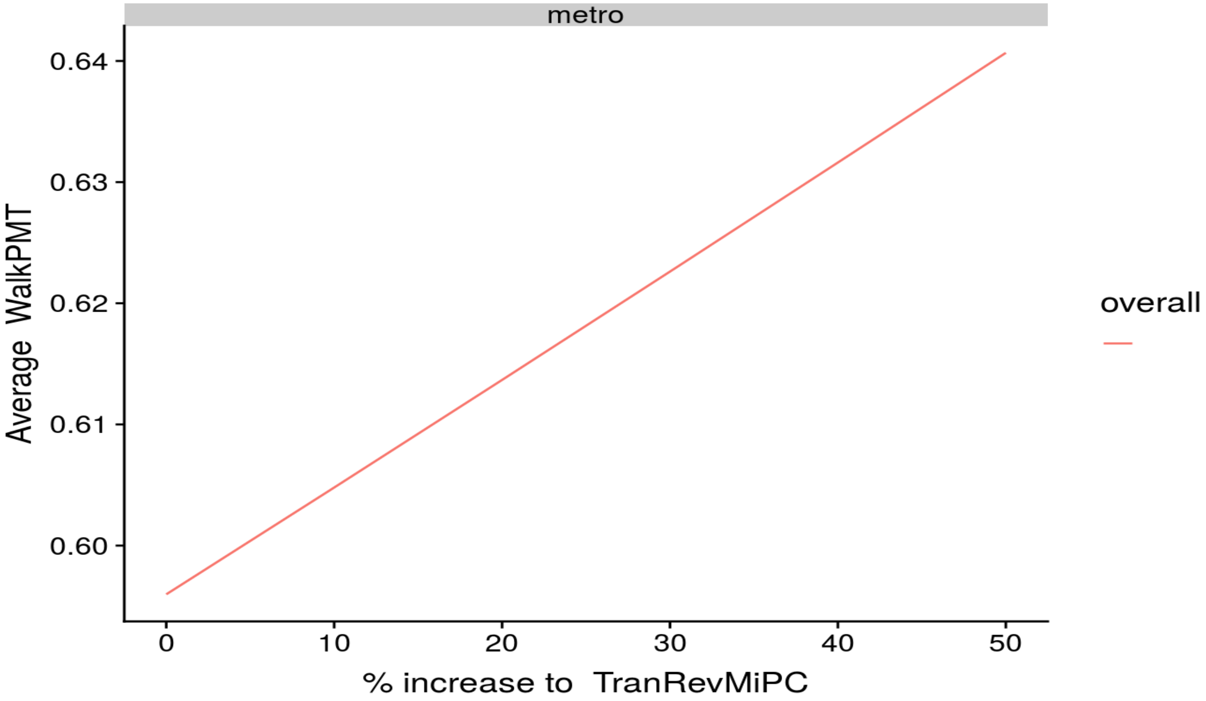
(b)



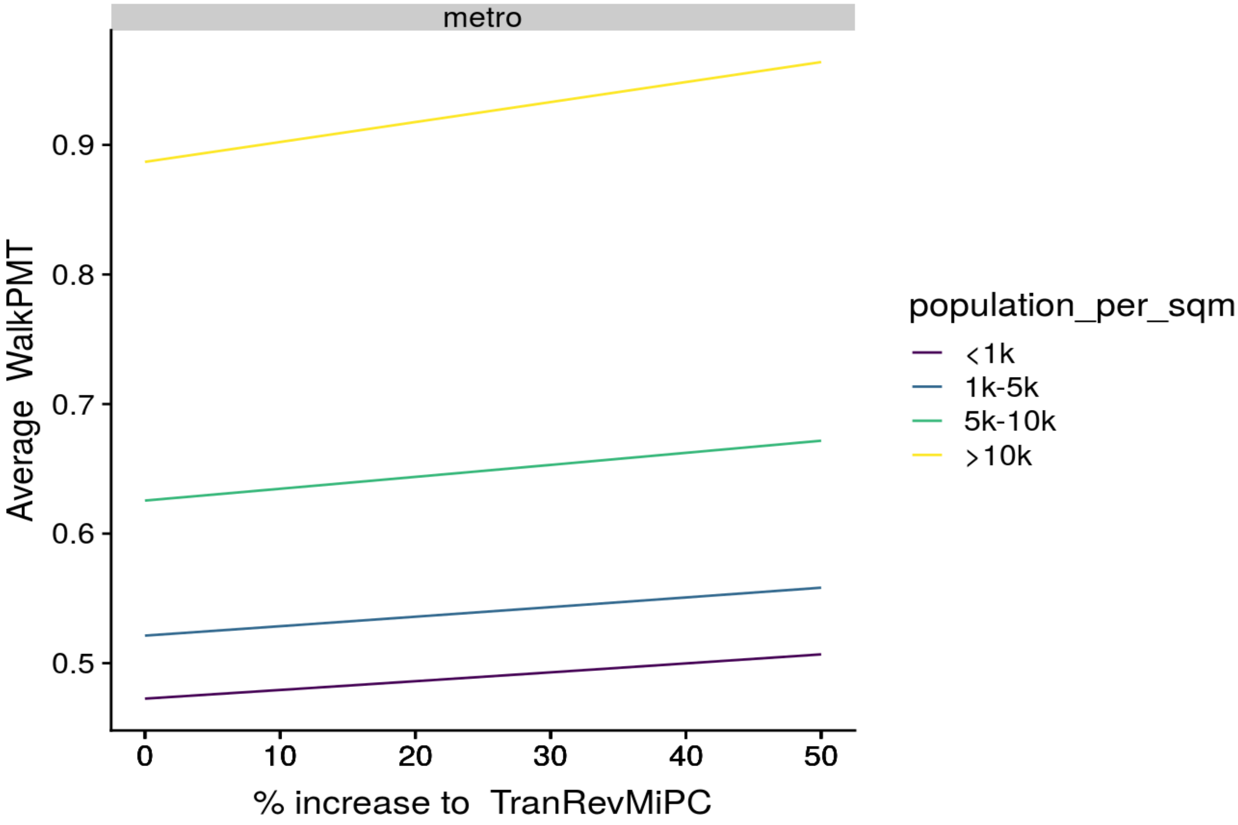
(c)

(d)

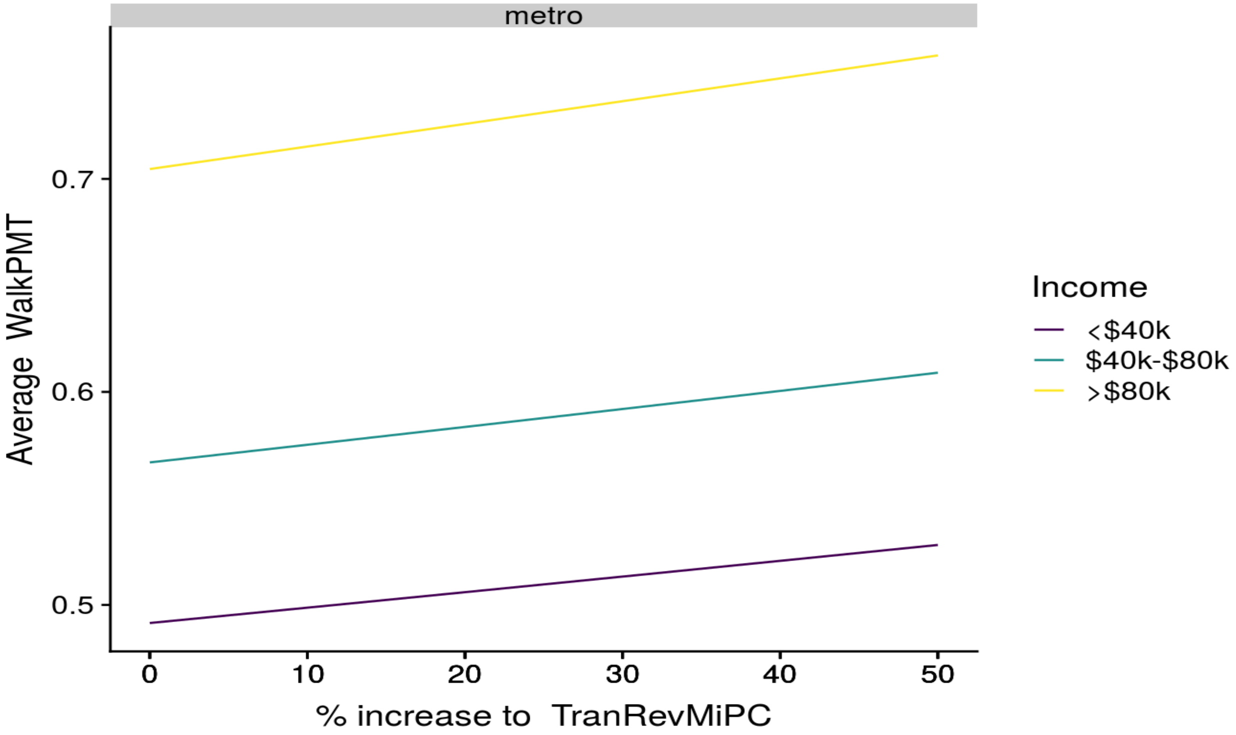
**Figure A.13 Elasticities of walking PMT with respect to freeway lane miles per capita: overall (a), segmented by density (b), income (c) and development type (d)**


metro
Average WalkPMT
0.64
0.63
0.62
0.61
0.60
0
10
20
30
40
50
% increase to TranRevMiPC
overall

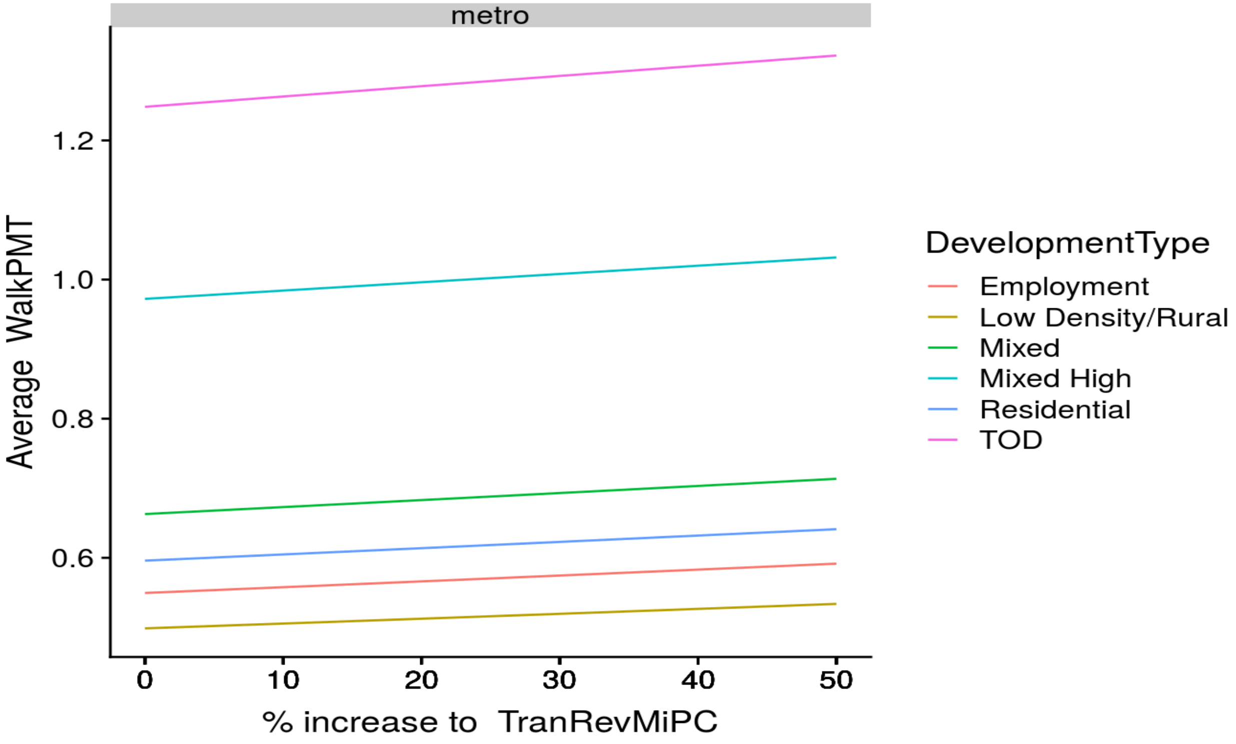
(a)


metro
Average WalkPMT
0.9
0.8
0.7
0.6
0.5
0
10
20
30
40
50
% increase to TranRevMiPC
population_per_sqm
<1k
1k-5k
5k-10k
>10k

(b)



(c)



(d)

**Figure A.14 Elasticities of walking PMT with respect to transit revenue miles per capita: overall (a), segmented by density (b), income (c) and development type (d)**

# APPENDIX B: RESPONSES TO VETRAVELDEMANDMM CONTRIBUTION REVIEW FEEDBACK

This appendix is adapted from responses to VETravelDemandMM Contribution Review Feedback.

1. Travis returns a bunch of R package warnings that should be addressed, such as 'DoPredictions: no visible binding for global variable 'model'.

Fixed with **commit 24502591e49646a936e0accdd6132c5698060a1e**.

2. The dependent data packages (NHTS2009 and SLD) should be submitted.

They will be included in a new/separate pull request after this PR is merged.

3. The overall VE project Travis.yaml script should be updated to include the new module and dependent packages in the automatic testing.

Done with **commit e643502731e0d26f4fe3ddeefbfd97005c3c8c33**

4. The estimation methods should be revised to follow VE conventions. Some of these suggested revisions need to be discussed with the project team since we're still figuring out how we all work together and incorporate additions.

The variable names in estimation code in data-raw/ have been revised to follow VE conventions in **commit 1b498d5760fac88c383705fd1c7c4bbf04a58080**. There may be other places that I am happy to work with the review team and incorporate any appropriate changes.

5. update Travis automated testing script to test the new package

Done with **commit e643502731e0d26f4fe3ddeefbfd97005c3c8c33**

6. Revise the documentation/software to let the user know that the NHTS2009, SLD, confidential data for estimation, and estimation script are exceptions to the guidelines for various reasons.

A Data section is added to the Introduction vignette describing the data sources and the fact that confidential NTHS information is not included in the package in **commit 6da6125cd696b17cc43302ee2a7df2899f0af871**.

7. add proof of ODOT release of ownership

Need Tara and Tony's help here.

8. vignette and/or cheat sheet summarizing estimated functions and dependent variables

A Variables Used in Models subsection is added to the "Introduction to VETravelDemandMM" linking to Tara's cheat sheet **commit 6da6125cd696b17cc43302ee2a7df2899f0af871**.

9. For the software revisions, I recommend splitting any functions which alter the VE framework (the 'helper functions') as a separate pull request, as Brian Gregor mentioned.

I believe there is some confusion here - there is no function in the package that alters the VE framework. We did talk about some functions that are potentially helpful/useful to other packages, which may be better living upstream in the VE framework code. However, we didn't decide where it should be. These functions are all in R/DoPredictions.R (and, potentially, data-raw/EstModels.R), which could be easily moved to another place once we decide it. I am not sure it needs to be a separate pull request. Again I am happy to work with the review team and incorporate any appropriate changes.

10. The documentation is really quite thorough, and the inclusion of the submitted manuscript (while I haven't read it) seems like an excellent addition.

11. I do have one minor comment about the documentation that I noticed in the Overview document of the package: The transit and walk TRFL models are called with the function R/PredictTransitTFL.R, not R/PredictTransitPMT.R (similar for the walk models).

Fixed with **commit 9232f91bbb47dfa10b2569623c997fd79bb5562f**

# APPENDIX C: VETRAVELDEMANDMM (VISIONEVAL TRAVEL DEMAND) IMPLEMENTATION

This appendix is adapted from documents for the VETravelDemandMM package implemented for VisionEval, which is being committed to VisionEval framework (https://github.com/gregorbj/VisionEval/pull/130).

# OVERVIEW

The VETravelDemandMM module is an R package that implements a module for the VisionEval framework to simulate multi-modal travel demand for individual households including - Annual Average Daily VMT (AADVMT) - Transit trips and PMT - Biking trips and PMT - Walking trips and PMT

It supersedes the Daily VMT and non-driving trips models in RSPM/GreenSTEP (and re-implemented for VisionEval as the VETravelDemand module).

The motivations for developing the new package include better policy sensitivities for non-driving modes and taking advantage of newer and better data sources available since the implementation of the RSPM/GreenSTEP model.

## Better Representation of Multi-Modal Travel

Since the primary focus of GreenSTEP is green-house gas emission, its travel demand module has a minimum representation of non-driving modes. As more non-driving travel and its associated benefits attract more attention from the public and policy-makers, there is need to understand the key drivers of multi-modal transportation choice and how non-driving travel responds to policies and investment decisions and to develop models that better represent the multi-modal travel for strategic planning. This module is developed in response to this demand.

## Updating Models with the Latest and Best Data Available

The current implementation of the travel demand module uses for model estimation the latest 2009 NHTS data joined with EPA’s Smart Location Database (SLD) for built environment information, the National Transit Database (NTD) for region-level transit supply, and HPMS for the region-level road network. Access to the confidential block group of household’s residential location allow these nationwide datasets to be joined at a very high resolution. In addition, to refresh the model estimation with the latest nationwide datasets, this new data provide a rich set of high-resolution built environment variables (the SLD includes more than a hundred block group-level built environment measures covering most of US).

Since 2009 NHTS has Annual VMT data for most households surveyed (more than half of them missing in NHTS2001), we took advantage of the data and modeled the AADVMT for households, instead of VMT from the survey day used in GreenSTEP.

## Rigorous Benchmark and Selection of Different Model Structures

There are various model structures used in the research literature to model non-driving travel. We reviewed the various model structures and used theoretical vigorousness and cross-validation to benchmark and select model structures.

## Taking advantage of the R infrastructure and new packages

The current implementation of the module takes advantage of the tidyverse suite of R packages, in particular, dplyr, for efficiency, concision and code readability. It also uses the purrr package for functional programming where feasible. Comparing with RSPM/GreenSTEP, the package uses model objects and method dispatch for predict calls, which eliminates the need to implement different model structures in the package.

## METHODS AND MODEL STRUCTURE

Here is a summary of existing and selected model structures:

- GreenSTEP Daily VMT (DVMT) Models (2-step models)
    1. binomial logit ZeroDVMT
    2. power-transformed linear regression of DVMT (for DVMT > 0)
- AADVMT Model for Annual Average Daily VMT (AADVMT)
    1. power-transformed linear regression of AADVMT
- TFL models for non-driving modes (2-step models)
    1. hurdle model of trip frequencies by modes (transit, walk, and bike)
    2. power-transformed linear regression of average trip length
- Daily person mile traveled (PMT) by (non-driving) modes models
    1. hurdle models of DPMT by modes (transit, walk, and bike)

Technical details of the model structures can be found in the estimation script for the corresponding model in data-raw. The actual functions doing the prediction for the module in R is model structure-agnostic - it is determined by the model objects saved in the model data frame in the data directory.

## Variables Used in Models

A Cheat Sheet created by Tara Weidner summarizes the estimated functions, independent and dependent variables in each model.

## DATA

This module provides default model parameters estimated with US nationwide data, and it is also possible to re-estimate model parameters with region-specific data. The main estimation data are drawn from two external data package (NHTS2009 and SLD, documented therein, (the plan is to commit them to the VisionEval repository) and data-raw/LoadDataforEstimation.R joins data from different data sources and creates a single household data frame for estimation. Data-raw/LoadDataforEstimation.R provides code and comments needed to replace the estimation data with region-specific data. However, since the residential block group information for households in the 2009 NHTS (essentially providing an additional block group id column to the households data frame and allowing NHTS to be joined with SLD) used in the estimation of the nationwide models is confidential and cannot be shared, users will not be able to directly run the estimation scripts in data-raw.

## USAGE

### Installation

The package can be installed from github using the devtools package:

```
devtools::install_github("gregorbj/VisionEval/sources/modules/VE
TravelDemandMM@develop")
# OR
devtools::install_github("cities-lab/VETravelDemandMM")
```

### Model Prediction

As a VisionEval module, the package provides 9 functions (in an R directory) that predict a range of travel outcomes for driving and non-driving modes:

- AADVMT (Annual Average Daily VMT): R/PredictAADVMT.R
- Bike PMT (Person miles travelled): R/PredictBikePMT.R
- Bike TFL (Trip frequencies and length): R/PredictBikeTFL.R
- Transit PMT: R/PredictTransitPMT.R
- Transit TFL: R/PredictTransitTFL.R
- Walk PMT: R/PredictWalkPMT.R
- Walk TFL: R/PredictWalkTFL.R

To use modules in the package with the default parameters, a user will add modules to visioneval::runModule:

```
#' @source \url{https://github.com/gregorbj/VisionEval/blob/9869
880c26802b57447c87c8e7a317df891714 98/sources/models/VERSPM/Test1
/run_model.R}

library(visioneval)

#Initialize model
```

```
#-----------------
initializeModel(
  ParamDir = "defs",
  RunParamFile = "run_parameters.json",
  GeoFile = "geo.csv",
  ModelParamFile = "model_parameters.json",
  LoadDatastore = FALSE,
  DatastoreName = NULL,
  SaveDatastore = TRUE
  )

#Run all demo module for all years
#---------------------------------
for(Year in getYears()) {
  runModule(ModuleName = "CreateHouseholds",
            PackageName = "VESimHouseholds",
            RunFor = "AllYears",
            RunYear = Year)
  runModule(ModuleName = "PredictWorkers",
            PackageName = "VESimHouseholds",
            RunFor = "AllYears",
RunYear = Year)
  runModule(ModuleName = "AssignLifeCycle",
            PackageName = "VESimHouseholds",
            RunFor = "AllYears",
            RunYear = Year)
  runModule(ModuleName = "PredictIncome",
            PackageName = "VESimHouseholds",
            RunFor = "AllYears",
            RunYear = Year)
  runModule(ModuleName = "PredictHousing",
            PackageName = "VESimHouseholds",
            RunFor = "AllYears",
            RunYear = Year)
  runModule(ModuleName = "LocateHouseholds",
            PackageName = "VELandUse",
            RunFor = "AllYears",
            RunYear = Year)
  runModule(ModuleName = "LocateEmployment",
            PackageName = "VELandUse",
            RunFor = "AllYears",
            RunYear = Year)
  runModule(ModuleName = "AssignDevTypes",
            PackageName = "VELandUse",
            RunFor = "AllYears",
            RunYear = Year)
  runModule(ModuleName = "Calculate4DMeasures",
```

```
            PackageName = "VELandUse",
            RunFor = "AllYears",
            RunYear = Year)
  runModule(ModuleName = "CalculateUrbanMixMeasure",
            PackageName = "VELandUse",
            RunFor = "AllYears",
            RunYear = Year)
  runModule(ModuleName = "AssignTransitService",
            PackageName = "VETransportSupply",
            RunFor = "AllYears",
            RunYear = Year)
  runModule(ModuleName = "AssignRoadMiles",
            PackageName = "VETransportSupply",
            RunFor = "AllYears",
            RunYear = Year)
  runModule(ModuleName = "AssignVehicleOwnership",
            PackageName = "VEVehicleOwnership",
            RunFor = "AllYears",
            RunYear = Year)
  runModule(ModuleName = "PredictVehicles",
            PackageName = "VETravelDemandMM",
            RunFor = "AllYears",
            RunYear = Year)
  runModule(ModuleName = "PredictDrivers",
            PackageName = "VETravelDemandMM",
            RunFor = "AllYears",
            RunYear = Year)
  runModule(ModuleName = "PredictAADVMT",
            PackageName = "VETravelDemandMM",
            RunFor = "AllYears",
            RunYear = Year)
  runModule(ModuleName = "PredictBikePMT",
            PackageName = "VETravelDemandMM",
            RunFor = "AllYears",
            RunYear = Year)
  runModule(ModuleName = "PredictWalkPMT",
            PackageName = "VETravelDemandMM",
            RunFor = "AllYears",
            RunYear = Year)
  runModule(ModuleName = "PredictTransitPMT",
            PackageName = "VETravelDemandMM",
            RunFor = "AllYears",
            RunYear = Year)
}
```

## Model Estimation

If a user needs to replace the default model parameters and/or structures, they will use the scripts in data-raw, following these steps:

1. Prepare data

   Replace data-raw/LoadDataforModelEst.R with their own script that loads and processes their own household data frame. The variables used in the current estimation are documented in the comments of data-raw/LoadDataforModelEst.R. Users can add, remove, or replace most of the variables.

2. Customize model formula

   Edit the corresponding model estimation script in data-raw/ to customize model formula for re-estimation. For example, if a user wants to re-estimate the AADVMT model, s/he would edit data-raw/AADVMTModel_df.R. Before modifying the formula, replace the line in the script source ("data-raw/LoadDataforModelEst.R") with your own script created in step 1.

   The estimation script uses the standard R model formula to specify models. Users can change the independent variables, the transformation of dependent variables, even model structure (model type) by modifying the formula.

   It is also possible (and recommended if the re-estimation is a specific region) to change the segmentation scheme. Most models in the package use metro status to segment data and estimate different models for each segment. The user can replace "metro" with any other desired variable for segmentation. If no model segmentation is needed, see data-raw/DriversModel_df.R and data-raw/VehiclesModel_df.R for examples of disabling segmentation.

3. Re-estimate and save estimation results

   After modifying the model formula, save the script and source it in RStudio (recommended) or an R console. This should re-estimate the model with the new formula and save the estimation results to data/. It is likely to take many iterations and troubleshooting before the model formula is ideal.

4. Modify prediction specification

   Once an ideal model formula is found and estimation results saved to data/, the user needs to edit the specifications in the R/Predict*.R script corresponding to the model being modified to be consistent with the model formula.

5. Rebuild and reinstall the package

Finally, the package is ready for **Build and Reload**. Once the Build and Reload finishes successfully, the re-estimated module to ready to use with visioneval::runModule (see section above).

## CODE REPOSITORY AND AUTOMATED TESTS

The source code of the VETravelDemandMM package is available on GitHub: https://github.com/cities-lab/VETravelDemandMM

Automated tests of the package including:

- package check with devtools::check(),
- package build and installation with R CMD INSTALL, and
- package tests in tests/scripts/test.R (with Rogue Valley data).

The automated tests are handled by Travis-CI and the current status of automated tests for the package is automatically updated.

## ADDITIONAL DOUMENTS

Results based on research for the SPR 788 project was presented at the TRB annual meeting:

Wang, Liming, Brian Gregor, Huajie Yang, Tara Weidner, and Tony Knudson, Regional Strategic Planning Model and the Development of a Multi-modal Travel Demand Module, Proceedings of the 97th Annual Meeting of Transportation Research Board, Washington, DC. January 7-11, 2018

A manuscript is currently under review for Journal of Transport and Land Use: - Development of a Multi-modal Travel Demand Module for the Regional Strategic Planning Model (manuscript under review)

A paper on the VETravelDemandMM package, as a part of the VisionEval session, is accepted for presentation at TRB's Innovations in Travel Modeling conference in Atlanta, GA in June 2018.